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Another Proposed Isthmian Canal

another Isthmian Canal route, which has not hitherto been surveyed by Government

engineers, but which is regarded by its advocates, as well as by some Senators and naval officers, as more advantageous than either of the routes now under consideration. This is the so-called "Darien-Mandingo route," which was, we believe, brought to the attention of the Paris Geographical Congress, with the San Blas, the Panama, and the Nicaragua routes, more than twenty years ago. A private corporation—the American Isthmian Ship Canal Company—has recently been organized for the purpose of bringing this route to the attention of the President and Congress, and it is reported that a bill will shortly be introduced providing for the construction of a Darien-Mandingo sea-level canal by private capital backed by a Government guarantee. The advantages claimed for this route by its advocates are briefly as follows: Its length—twenty-nine and one-half miles—which is less than that of any other route; good deep-water harbors exist on both sides; there are to be no curves, dams, or locks; all of the difficulties arising from the necessity of controlling rivers subject to disastrous floods are avoided. It would involve a tunnel a trifle less than five miles long through granite mountains; but the company claims to have received propositions from responsible contractors, backed by suitable financial guarantees, to do this part of the work in a comparatively short time and at a moderate cost. Outside the tunnel there are no cuts deeper than eight to fifteen feet, and no engineering difficulties other than those that would be met with in any level tropical country. The tunnel can be excavated in less than two years and the canal finished in four years, at a cost estimated by its projectors of less than \$100,000,000. The proposed tunnel is to be wide enough and high enough to permit the passage of the largest vessels now afloat; it is proposed to light it by electricity and ventilate it through vertical shafts, and to draw ships not using their own steam through it by

electric traction. The company has purchased a strip of territory twelve miles wide entirely across the isthmus on this route; but we do not know how its rights and title, for canal purposes, are affected by the concession of the Colombian Government to the Panama Company.

Arguments Pro and Con Such are the salient features of the plan, as it is presented by its advocates. They claim that it was favorably regarded by President McKinley, and has the support of Senator Hanna and other prominent men. Tunnels for canals are not new. The Biwa Lake canal in Japan is carried through six tunnels, one of them having a length of 8,040 feet; but it admits only vessels without masts. The fact that, as reported, it is proposed to build this canal by private capital guaranteed by the United States is, in our judgment, fatal to it in its present form. The judgment of the country has definitely and we hope finally determined on the construction, ownership, and control of the Isthmian Canal by the Government; no other proposition is now open for consideration or ought to be considered by Congress. Moreover, this route was carefully considered by the Isthmian Canal Commission, and its expense estimated approximately at \$289,000,000, a more probably accurate estimate than the vague one of \$100,000,000 by the American Isthmian Ship Canal Company. The country will not, in our judgment, willingly tolerate any proposition to substitute for a Governmental canal one owned by a private corporation; nor patiently endure a further postponement of the canal question until this route can be debated by Congress, after the thorough consideration of all competing routes by the Isthmian Canal Commission and its unanimous preference for the Panama route. We report this route and the arguments for it to our readers, but we do not at the present writing take it very seriously.

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Correspondence.

The Canal Problem.

To the Editor of the SCIENTIFIC AMERICAN:

I have read, with a great deal of interest, the various articles in your valuable paper of the 18th instant, bearing on the leading question of the day, viz., the canal from the Gulf of Mexico to the Pacific Ocean; and, as far as your explanation goes, would prefer the route across the Isthmus of Panama rather than at Nicaragua, but I wish to inquire if you have not omitted to mention two very important matters?

In the first place, is not the grant from Colombia to the present canal company only temporary, giving to the company the use and control of the canal for 99 years from and after its completion, when all right, title and interest in it will pass to Colombia in perpetuity? If such is the case, will not the same rule apply to the United States as the successor of the Panama Canal Company? And will that be a satisfactory condition to the people of this country in which to place this nation? Or is it not the almost universal feeling here that the United States, if it advances the money to build the canal, should be the exclusive and perpetual owner and manager of the same, allowing vessels of all nations to pass through in the interest of commerce, but reserving the exclusive control and management, especially in case of war in which this country might happen to be involved?

The other point I desire to mention is that of the French or other bondholders and stockholders who, I believe, hold bonds and stocks to the extent of about \$300,000,000, and whose interests, as I understand, will not be settled or satisfied by the payment of the \$40,000,000 demanded by the canal company, and who will consequently claim, or can claim, the payment of their bonds or stocks, provided any party of sufficient responsibility should become the owner of the canal.

If these are the facts, will it not be necessary, or at least wisdom, for the United States before entering upon or considering any proposition leading to the purchase of the interests of the Panama Canal Company to first require that these questions be settled in a manner satisfactory to this country, and then consider the advisability of making the purchase? As I understand it, no questions of this nature are involved in the Nicaragua route, and the point will be which route presents the least objections together with the most advantages, not only in a financial way, but also in all other ways which might be presented?

If the statements, as given, are correct, will they not have much bearing on the case when taken in connection with the statements in the articles in your paper?

C. E. GILLESPIE.

Edwardsville, Ill., January 22, 1902.

[The Colombian government, to assist the transfer of the Panama property, has waived the prohibitions under the 99-year lease, and has offered the United States absolute control over a strip, five miles wide, along the route of the Panama Canal, the term of lease to be 200 years, with the right of renewal. After the old company failed its property passed into the hands of a liquidator (equivalent to our receiver) and the interests of the old company, which called for the payment of 60 per cent of the profits of the new company, are still under the care of the liquidator, who has agreed to the proposition to sell the Panama properties to the United States for \$40,000,000.—Ed.]

The Armament of Our New Warships.

To the Editor of the SCIENTIFIC AMERICAN:

Your special naval number suggests certain reflections on the progress of our navy and the direction in which it is developing of a somewhat pessimistic character. Heavy armament in proportion to displacement has characterized the American navy from its earliest days, and our naval constructors appear to be adhering faithfully to this tradition. The gun power of our new vessels is all that can be desired, but are we not sacrificing defensive strength to a dangerous degree in order to obtain this offensive power? What may have been a wise policy in the days of wooden sailing vessels may well be a very foolish policy in the day of steam-driven ironclads.

The "Georgia" class may fairly be taken as a type of the latest development of the heavy battleship, the ideal fighting craft of our naval constructors. Now, it is clear from your description of this class:

1. That its belt armor is not thick enough to resist a 12-inch shell which has traveled two miles—a greater distance than that at which naval battles are expected to be fought. Even an 8-inch shell would penetrate it at 2,000 yards.

2. The same remark applies to the armor of barbettes and turrets.

3. It is also true that the casemate armor would be penetrated at two miles by the projectiles from guns of the same caliber as those which it is supposed to shield.

It is obvious that a battle between one of these

vessels and another of equal strength would be determined either by a lucky shot penetrating the belt armor and disabling the motive power or by the successive disabling of the guns and the destruction of their crews—the armor of the gun positions being too thin to protect them from the fire of any but the secondary batteries; and both vessels would likely be damaged beyond repair, at least as long as that war lasted.

Is it not possible for our naval constructors to devise a more efficient fighting machine by increasing its powers of resistance? Our earlier battleships had armor 18 inches thick on belt and turret, and were built to resist guns of much less power than the gun of to-day. Krupp plates, it is true, are 25 per cent stronger than the Harvey plates, but the attacking gun has increased in power even more. If armor is of any value at all it would seem obvious that it should increase in thickness as the gun increased in penetration; if not, it had better be discarded and the weight put into additional guns.

The nation that will ultimately be victorious on the sea (if the victory is attained by the gun and not by submarines and other devilish novelties) will be the one that first appreciates the fact that one gun behind a shield that cannot be penetrated, on a vessel that cannot be sunk or crippled in its motive power, is more effective than a dozen which are imperfectly protected on a vessel which can be rendered helpless by a single lucky shot.

To illustrate, let a vessel of the type of the "Georgia" be opposed to one of equal displacement but one deck less in height. Raze the double turret of the "Georgia," discard all its 8-inch guns and half of its 6-inch and smaller guns and put the weight so saved into heavy armor, say, 18 inches for barbette and turret, 8 inches or 9 inches for casemate and 20 inches for belt armor. Such a vessel could be pounded all day by the "Georgia" without serious injury, while every shot it sent could go through the "Georgia's" casemates, and every 12-inch shell could penetrate turret, barbette and belt. Can there be any doubt as to the outcome of such a fight?

It is no answer to say that other nations are sacrificing defensive to offensive power in the same way that we are. While we were learning to build ships of war it was well enough to follow foreign models, even copying their errors. We have learned all they know and ought by this time to be improving on their methods, and no greater improvement can be made than to construct vessels that cannot be sunk and arm them with guns that are nearly, if not quite, proof against attack.

T. W. BROWN.

Chicago, December 30, 1901.
[Our correspondent's argument in favor of heavier armor would have more weight if it were certain that all projectiles will strike normal to the surface. Unless they do so they will not perforate the armor mentioned by him at the ranges assumed. As a matter of fact, only a very small percentage of the shots fired will strike at all (two per cent at Santiago), and probably less than ten per cent of these will be normal hits.—Ed.]

THE DARIEN OR SAN BLAS TUNNEL CANAL ROUTE.

In view of the fact that an expert commission has been engaged for the past two or three years in a thorough examination of all possible routes for a canal across the Isthmus, and that this commission included some of the most distinguished engineers that could be gathered together for the purpose, and in view, further, of the fact that over one million dollars has been expended in making this examination so absolutely thorough as to render any further examination superfluous, one would have thought that the report, as recently given to Congress, would have been accepted as final, and that there would have been an end to suggestions for the sending out of more surveying parties into a territory that has been so thoroughly explored.

Therefore, we much regret to see that a joint resolution has been offered to Congress for the appointment of a Board to examine into the practicability and cost of a tunnel ship canal by what is known as the San Blas route. We regret it, not so much on account of the expense involved, for this is comparatively insignificant, an appropriation of only \$15,000 being asked for the purpose, but because the mere proposal that such a survey be made is disturbing, and calculated to confuse the general public. The suggestion that there is anything more to learn about San Blas will be taken at its proper worth by practical engineers, and by that large and increasing section of the public who by studying the canal question for themselves, have grasped its main details, and are able to form an intelligent individual opinion as to where the canal should be built. It is upon the average citizen, who has not the time or opportunity to gain anything more than a superficial knowledge of the canal problem, that this continual agitation of the question of routes is so confusing. Evidence of this is shown in the letters which reach the editor's desk, asking whether a short tide-level canal, with a tunnel through the hills, is not preferable, even to the short and easily-navigated Panama canal. It is impossible to reply to these correspondents in detail, so we take this opportunity of saying that the possibilities of constructing a tide-level canal by tunneling through the hills were thoroughly investigated by the Isthmian Canal Commission, and estimates were given for the cost of such canal at four different routes; one of them at San Blas and three of them on what is known as the Caledonia route. It was found that at San Blas 4.2 miles of tunnel would be necessary; while in the Caledonia district 1.6 miles would be required on the Sarsfield location, on the Aglaseniqua location 3.6 miles, and 4 miles of tunnel on the third alternative location. It is certain that the advocates of a tunnel canal have no adequate idea of the stupendous nature of the excavation required. To accommodate steamers of the size that will pass through the Panama Canal a vast cavern would have to be blasted through the mountains (the term tunnel is quite inadequate to express its magnitude, so absolutely insignificant in comparison is the ordinary railroad tunnel), which would be 165 feet in height by 130 feet in width, and the whole of it would have to be lined with mass of concrete from 5 to 7 or 8 feet in thickness. A single mile of this tunnel would cost \$22,500,000 to construct, and the 4.2 miles of tunnel necessary at San Blas would cost alone \$94,500,000. The approach to the tunnel at each end would necessitate the construction of an enormous open cut, deeper in places than the Culebra cut at Panama, which, with the other excavation along the 37 miles of the canal, would bring up the total cost of excavation outside of the tunnel to \$132,800,000. The total cost of the canal along this route would be \$289,770,000.

Now, it is not by any means certain that the estimate of \$22,500,000 per mile for the construction of the tunnel would be sufficient to cover the actual cost, for the engineers in making this estimate, assumed that they would meet with material that was favorable for excavation; that is to say, that there would be no material encountered that would tend to slide as soon as it was disturbed by excavating. If such material should be encountered, it is perfectly certain that the engineers would be helpless in the presence of it. In proof of this we refer our readers to the

FEBRUARY 22, 1902.

account, in our issue of February 8, of the construction of the Aspin tunnel on the Union Pacific Railroad. In the excavation of this work, which is absolutely insignificant compared with the enormous cavity which would have to be opened up at San Blas, the pressure of the sliding earth was such that twelve-inch shoring timbers were splintered into match-wood and heavy steel I-beams were twisted out of shape. The mere possibility of encountering such conditions would render it absolute folly to commence the construction of a tunnel of this magnitude in any location, and especially in the Central American regions, which are subject to volcanic disturbances.

PANAMA OR NICARAGUA—WHICH?

SCIENTIFIC AMERICAN

[Entered at the Post Office of New York, N. Y., as Second Class Matter. Copyright, 1902, by Munn & Co.]

Vol. LXXXVI.—No. 3.
ESTABLISHED 1845.

NEW YORK, JANUARY 18, 1902.

[\$2.00 A YEAR.
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Panama Canal—Length, 49 Miles. Time of Transit, 11 Hours 14 Minutes.

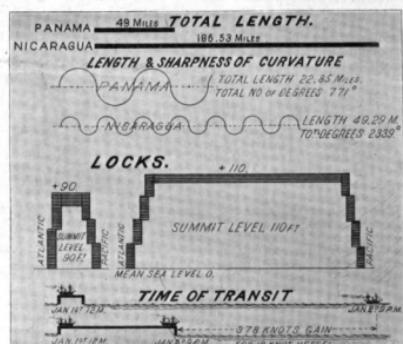
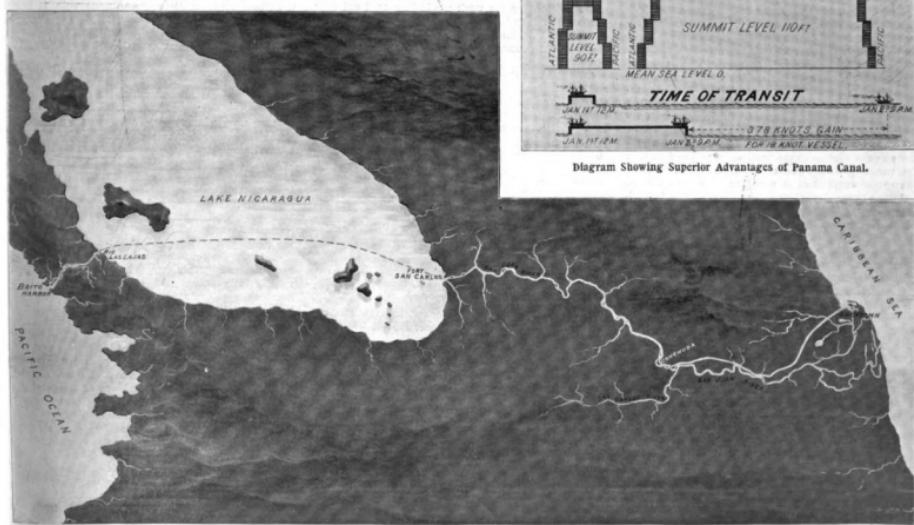


Diagram Showing Superior Advantages of Panama Canal.



Nicaragua Canal—Length, 186.5 Miles. Time of Transit, 33 Hours.

COMPARISON OF THE PANAMA AND NICARAGUA CANAL ROUTES.—[See page 38.]

SCIENTIFIC AMERICAN

ESTABLISHED 1845



THE Isthmian CANAL—HISTORICAL.

NICARAGUA.—The first actual survey for a canal at Nicaragua was made by an American, Col. A. W. Childs, in 1850 to 1852. The project as outlined by him has been the basis for all subsequent locations; the route selected in his survey differing indeed but very little from that which is now recommended by the Isthmian Canal Commission. Childs recommended a summit level, in which was included Lake Nicaragua, 108 feet above sea level, this level to be reached by twelve locks on the eastern side and thirteen locks on the western side. The canal was to have a depth of 17 feet and a bottom width of 50 feet, and the total cost was to be \$31,538,319. Then followed a survey in 1872 under Commander E. P. Lull, U. S. N., in which the lake was to be held at a minimum summit level of 107 feet, reached by eleven locks on the western and by ten locks on the eastern side of the summit. The depth of the canal was to be 36 feet and the cost was estimated at \$65,722,137. Eleven years later another survey was made, this time by A. G. Menocal, Civil Engineer, U. S. N., the object of the survey being the relocation of the Lull survey with a view to cheapening the cost. The principal changes consisted of the creation of a summit level, which extended from a dam in the river west of Lake Nicaragua to a dam some 65 miles down the San Juan River from the lake. The canal was to leave the San Juan just above this dam and be carried by a short cut through the hills to the Caribbean Sea. The Maritime Canal Company was formed in 1889 to construct a canal on the lines of the Menocal survey. The total estimate for this canal with a 28-foot depth of water was \$67,000,000. After doing more or less work the Maritime Company ceased operations in 1893 for lack of funds. In 1895 Congress appointed the Ludlow Commission to examine and report on the Maritime Canal Company's project. This Commission reported that the difficulties of building the canal had been underestimated; and they submitted an estimate of their own which placed the cost of completion at \$133,472,893. At the same time the Board suggested a more thorough examination of the locality. In response to this recommendation the Admiral Walker Commission was appointed; and in due course it reported that the canal would cost a maximum sum of \$140,000,000. It was about this time that the government awoke tardily to the realization of the fact that the canal question was a wider one than that of Nicaragua alone, and a new board, known as the Isthmian Canal Commission, was appointed to investigate every possible route across the Isthmus and definitely determine which was the best. A digest of this report will be found elsewhere in this issue, and in more extended form in the current issue of the SUPPLEMENT.

PANAMA.—It will be a surprise to many who believe that American interests are necessarily and exclusively identified with Nicaragua to know that the Panama route was surveyed by Commander Lull in 1875, that he recommended the construction of a 26-foot canal with a summit level of 124 feet above mean tide level, and that this route was located very much on the same route as that adopted by the present Isthmian Canal Commission. He estimated the cost of this canal at \$94,511,360. In 1879 an International Congress met in Paris and recommended the building of a sea-level canal from Colon on the Atlantic to Panama on the Pacific, the work to be completed in twelve years at a cost of \$240,000,000. Work was begun in 1881. An enormous amount of plant was purchased, 15,000 laborers were imported, and with the most incomplete data to work upon, the De Lesseps people rushed into the most stupendous engineering undertaking of the age. Yellow fever, floods, incompetence, unparalleled fraud and dishonesty, coupled with the impossible nature of the undertaking itself, soon brought about the inevitable disaster, and in 1889 a receiver was appointed, who found that securities to the amount of \$435,000,000

had been issued and \$246,000,000 had been squandered. In 1894 a new company was formed for the purpose of completing the canal. They determined to abandon the scheme for a tide-level canal and, instead, adopted a plan for a canal 29½ feet deep with a summit level of 97 feet, a second level of 68 feet and a third of 33 feet above the sea. The Chagres River was to be controlled by means of a dam at Bohio, forming a navigable lake in the valley of the Chagres, and another dam further up the Chagres River, which was to supply water to the summit level. An International Technical Commission of Engineers examined the plans of the new company and pronounced them perfectly feasible, the estimated cost of completing the canal being set down at \$102,400,000. Our own Isthmian Canal Commission propose a 35-foot canal, with a 90-foot summit level and three locks, which they estimate can be built for \$144,233,358. The latest step of importance connected with the canal has been the offer of the Panama Company to sell its property for the sum of \$40,000,000.

THE CANAL FROM THE ENGINEERING STANDPOINT.

The report of the Isthmian Canal Commission has swept away from the whole canal question a mass of misconceptions and misstatements with which it has been hitherto clouded. After a careful perusal of the report one is impressed with the conviction that the physical obstacles to the construction of a canal either at Nicaragua or Panama have been mastered; that the uncertainties have in a large measure disappeared; and that, judged from the standpoint of construction and subsequent maintenance and operation, Panama offers decidedly the better route.

1. In the first place, the Panama region is much better known and understood; the observations extend over a longer period; the surveys have been considerably more elaborate and complete; the climatic conditions are better known; and work having been opened up along the whole route and prosecuted with more or less energy for twenty years, the nature of the soil, its action when exposed to the weather, and in the process of handling is, by this time, well understood.

2. At Panama there is a well-built railroad throughout the whole length of the canal, terminating on each ocean in a good harbor with ample wharf and dockage facilities. Should the United States determine to build this canal, contractors could go down and commence work at once, for good housing accommodation is already on the ground for an army of from 15,000 to 20,000 laborers. At Nicaragua, on the other hand, entirely two new harbors would have to be created, at a cost of \$3,750,000, and 100 miles of double-track railroad would have to be constructed at a total cost of \$7,575,000. In fact, two years' time and \$11,000,000 of money must be expended before the actual construction of the canal itself could be commenced on any adequate scale.

3. At Nicaragua the work would be spread out over 183 miles of distance, whereas at Panama it would be concentrated within a distance of 49 miles—a fact which would conduce greatly to facility and economy of construction.

4. At Panama the plan of control of the flood waters and of maintenance of the summit level is very much simpler than at Nicaragua. At Nicaragua a 3,000-square-mile lake and 60 miles of canalized river have to be maintained at a predetermined level, alike in periods of drought and heavy rainfall; while a flow of 200,000 feet per second of water has to be controlled in the San Juan and San Carlos Rivers. At Panama, on the other hand, the problem involves the control of a single river, with a maximum flow of 75,000 cubic feet per second, and by the erection of a single dam the flood waters of this river are conserved in a summit lake, the conditions of whose regulation are accurately determined. At Panama the problem is relatively far less stupendous, and the engineering and general hydraulic data are better known.

5. At Nicaragua there is a 110-foot summit and seven different levels, involving the construction and operation of eight widely separated locks, whereas at Panama there are but two levels and three sets of locks, and the summit level is 20 feet lower.

6. The total length of the Nicaragua Canal is nearly four times that at Panama, and the time of transit is longer by about 22 hours, the respective periods being 33 hours for Nicaragua and 11 hours 14 minutes for Panama, and although this difference is offset in the case of voyages between certain ports by the fact that the distance from port to port by Nicaragua is less than it is by Panama, it must be remembered that a ship when sailing in deep water is undergoing fewer risks than when she is navigating a tortuous and shallow artificial canal.

7. The risks of operation are considerably less at Panama, for the reason that vessels will spend far less time within what might be called the "danger zone," this last being that portion of the canal which is above tide level. The danger zone at Nicaragua will be 176 miles in length; at Panama, on the other hand, it will

extend for only 23½ miles. This is a most important consideration for vessels of the merchant marine, and it has an even more important bearing upon the interests of the navy.

8. Finally, while the time for the completion of the two canals is the same, the cost of Nicaragua, now that the Panama Company has offered to sell its property for \$40,000,000, is \$5,630,700 greater. To this must be added the fact that a canal at Nicaragua would cost \$1,300,000 more every year to maintain and operate.

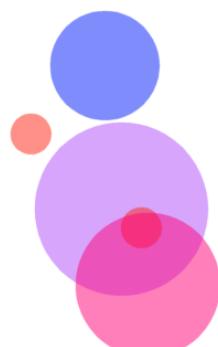
THE CANAL FROM THE STANDPOINT OF COMMON SENSE.

The great Isthmian Canal problem has reached a stage at which it needs only the exercise of a little common sense for its satisfactory solution. The question of the proper location for the canal is first and last one of engineering. In considering it, the American people should remember that whatever of sentiment, whatever of prejudice, whatever of so-called patriotism or national prestige has been allowed to entangle itself in this question, ought to be entirely swept away, and the problem looked into, weighed, judged and a final decision reached purely on the physical and engineering facts as they have been determined by our government engineers and presented to the American people for their decision in the recent most able, comprehensive and easily understood report.

We have no hesitation in saying that if anyone who is interested in the Isthmian Canal problem will read the digests and analysis of this report as presented in the current issues of the SCIENTIFIC AMERICAN and SUPPLEMENT, he will come to the conclusion that judged on the grounds of practicability of construction, security, permanence, convenience and ease of operation, and cheapness of first cost and maintenance, the Panama Canal as designed by our engineers is by far the better scheme. Having said this one has said all; but if it be suggested, as has lately been frequently done, that Nicaragua has exclusive claim upon our national interest and sympathy, it must be replied that the first complete survey at Panama was made, as we have shown elsewhere, by an American naval officer for the American government, and that over half a century ago this country concluded a treaty with New Granada (now the United States of Colombia) guaranteeing the perfect neutrality of the Isthmus at Panama as a highway from the Atlantic to the Pacific. The solemn stipulations of that treaty have remained in force ever since, and only within the last few months our government, acting under the stipulations of this treaty, landed troops for the protection of the Panama Railroad.

Congress has grown so used to considering Panama as a French undertaking, that it is only now beginning to realize that if we take hold of the Panama scheme under our own terms of purchase, it becomes as truly an American enterprise as would the construction *de novo* of a canal at Nicaragua.

Although the Hepburn Canal Bill has been passed in the House by a practically unanimous vote, it is significant that an amendment authorizing the President to negotiate for the Panama as well as the Nicaragua route was lost by 102 votes to 170. This result would indicate that if the Senate should send the bill back to the House, amended so as to provide for building the canal on the Panama route, the House would accept the revision.



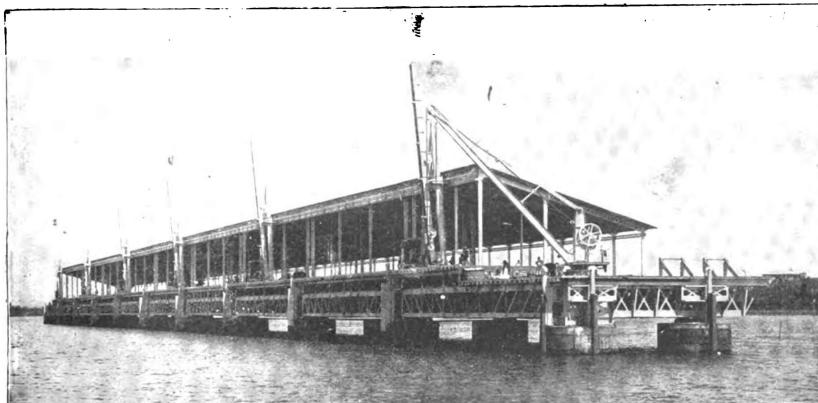
THE Isthmian CANAL CONTROVERSY

SCIENTIFIC AMERICAN
SUPPLEMENT. No 1359

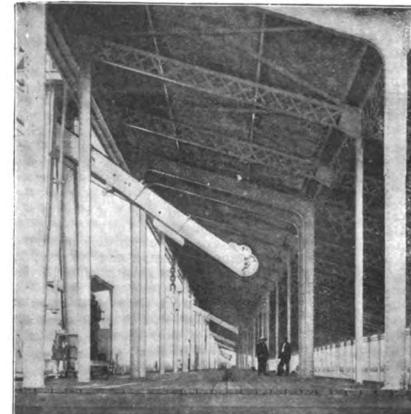
Vol. LIII. No. 1359.

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January 18, 1902.



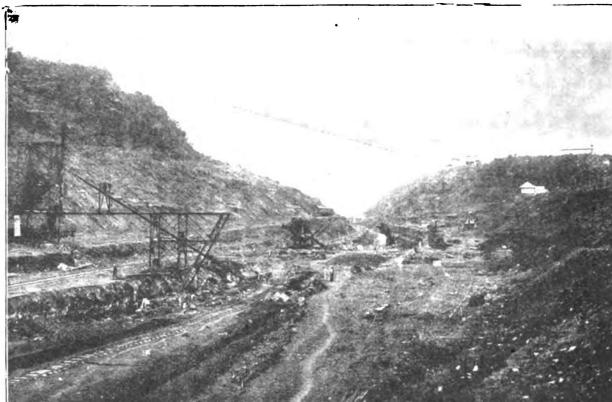
1.—IRON PIER AND SHED AT LA BOCA, AT THE INSHORE END OF MARITIME SECTION OF PANAMA CANAL ON THE PACIFIC.



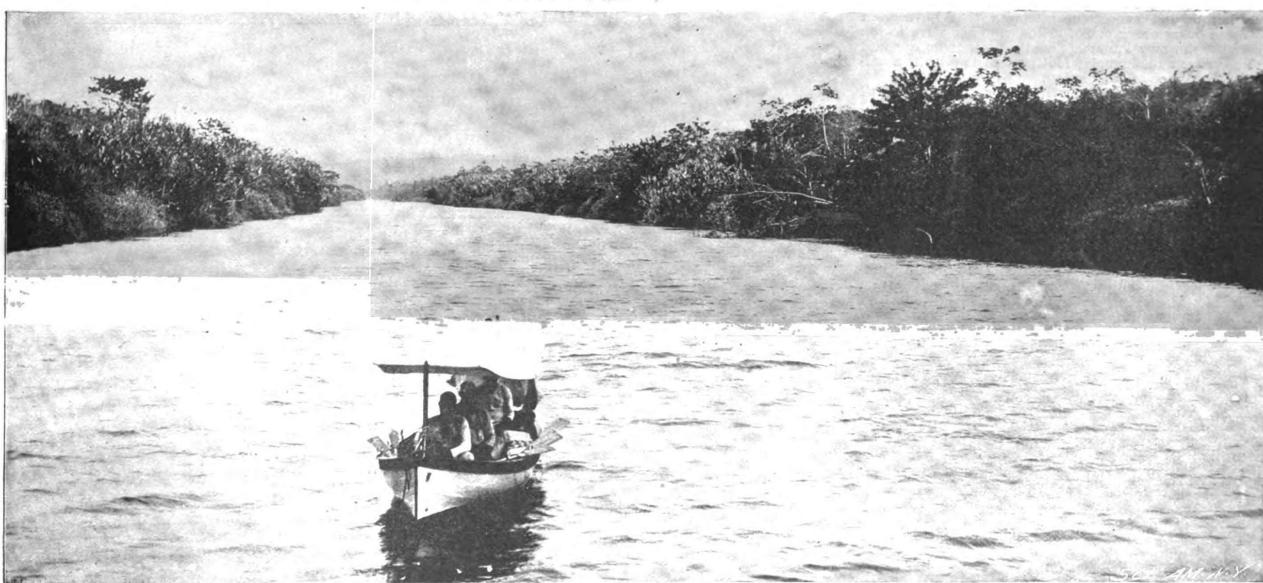
2.—VIEW LOOKING THROUGH INTERIOR OF LA BOCA PIER SHED. LENGTH, 891½ FEET.



3.—BOHIO—SITE OF LOCKS AND DAM. CHAGRES RIVER IN THE FOREGROUND. LOCKS WILL BE BUILT IN THE ROCK CUT BEYOND THE RIVER.



4.—GREAT CULEBRA CUT, 34 MILES FROM ATLANTIC. DOTTED LINE SHOWS ORIGINAL SURFACE OF MOUNTAIN.



5.—COMPLETED CANAL, 10 MILES FROM ITS ATLANTIC ENTRANCE. CANAL IS EXCAVATED TO WIDTH SHOWN FOR 15 MILES, OR UP TO BOHIO.
THE NEW PANAMA CANAL—CONDITION OF THE WORK IN 1898.

THE IsthMian CANAL CONTROVERSY.

In response to a large number of requests for information regarding the present status of the Isthmian Canal question, we are devoting the present issue of the SUPPLEMENT to this important subject. Also, in the current issue of the SCIENTIFIC AMERICAN will be found a summary of the respective merits of the Nicaragua and Panama schemes, together with some maps and diagrammatic comparisons. We have endeavored to treat the matter so comprehensively that those of our readers who have not the time to read up the vast amount of literature which has appeared on the question, may still be able to obtain an intelligent grasp of the situation and judge for themselves of the relative merits of the two routes proposed.

We published in the SCIENTIFIC AMERICAN some three years ago two articles upon the Nicaragua and Panama canals. They appeared at a critical time in the history of these canals. The new Panama Canal Company plans had just received the unqualified indorsement of a technical commission composed of leading engineers from various countries, in which were included several prominent hydraulic engineers from the United States. At the same time the old Maritime Canal Company was endeavoring to commit the United States government to the financial indorsement and backing of their canal at Nicaragua; and of two expert commissions appointed by the United States government to report upon these plans, one had criticized them adversely and raised the estimated cost of construction by 100 per cent, while the second commission was known to have practically indorsed the findings of its predecessor. In the two articles above referred to, the plans of the new Panama Canal Company, of the Nicaragua Maritime Canal Company, and of the United States government commissions were fully illustrated and described. As these articles accurately describe the present conditions at both Panama and Nicaragua, we reproduce them with additional illustrations in the present issue of the SUPPLEMENT.

Shortly after the publication of these articles, the government appointed the Isthmian Canal Commission and voted one million dollars to defray the expenses of a thorough engineering investigation of the whole isthmus, for the purpose of determining the best location for a canal. The third and concluding chapter of this issue consists of a careful digest giving the essential features of this report. It must be evident to every impartial reader that while the excessive price (over \$100,000,000) demanded by the new Panama Canal Company for the property caused the commission to recommend the construction of the Nicaragua route, the engineering advantages lie almost entirely with the Panama route. Moreover, as we go to press the new Panama Company is reliably reported to have made an offer of its properties for \$40,000,000. This sum added to the cost of completing the Panama Canal (\$144,233,358) would make the total cost \$184,233,358 as against a total cost of \$189,864,062 to build the Nicaragua Canal.

THE NEW PANAMA CANAL.

THERE is a broad difference between the Panama Canal as it actually is and the Panama Canal as it exists in the public mind. It would be difficult to find another great undertaking about whose present status there is so much general ignorance or positive misinformation as there is concerning the artificial waterway with which Ferdinand de Lesseps attempted to join the waters of the Atlantic and Pacific Oceans. It is a matter of history how the distinguished Frenchman, emboldened by his success in cutting the Suez Canal, undertook to open a great sea-level cutting through the mountains of the Panama Isthmus (see profile, page 21777), and failed—the physical difficulties of the project, assisted by gross corruption on the part of the promoters, serving to bankrupt the company when only a fragment of the sea-level scheme had been completed. The odium of that ill-considered and worse executed project still attaches in the public mind to the Panama Canal as such; and it is only the small minority, who have followed the subsequent course of events on the isthmus and are familiar with the heroic and successful attempts that have been made to bring order out of chaos, who are alive to the fact that the new Panama Canal project is on a sound engineering and financial footing and is within a calculable distance of completion.

The present article is written for the purpose of putting the public in possession of the facts regarding the present status and future prospects of this undertaking. In view of the fact that one canal at the isthmus will be amply sufficient to accommodate the traffic, the question of the completion or abandonment of the Panama scheme becomes of supreme importance in considering the advisability of building a canal on the Nicaragua route, for the construction of two practically contiguous canals would mean the bankruptcy of both.

HISTORICAL.—In 1879 an international congress met in Paris, and, after investigating various routes, recommended the building of a sea-level canal from Colon, on the Atlantic, to Panama, on the Pacific. Many of the best informed members of the congress, it should be said, considered that a sea-level scheme presented too many difficulties and advocated a canal with locks; but the influence of M. de Lesseps prevailed and the sea-level route was adopted. The calculated time for completion was set at twelve years, and the cost, including interest on capital, at \$240,000,000.

Now, when it is stated that the route of the proposed canal followed for over twenty-five miles a river which in the rainy season is subjected to enormous freshets, and that in passing through the Cordillera mountains an excavation 8 miles in length and varying from 100 to 325 feet in depth had to be made, it is evident that the first duty of De Lesseps was to secure the results of careful gaging of the rainfall, and to make elaborate borings along the route of the canal to ascertain the nature of the material to be excavated. Neither of these precautions was taken, or if taken, were so incompletely carried out as to leave the engineering features of the scheme very much in the air.

Work was begun in 1881. A large amount of the

capital of the company was swallowed up in purchasing and placing along the line the necessary plant, in constructing shelter for 15,000 laborers, and building the necessary workshops and hospitals. The first opening up of the surface soil induced an appalling

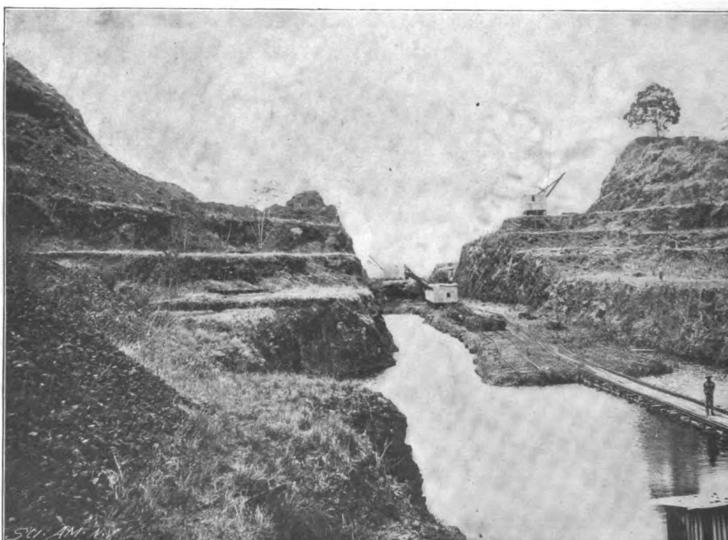
amount of sickness, and the enormous floods of the Chagres River proved altogether beyond the control of the engineers. Moreover, the upper layers of material in the great Culebra cut proved to be of a treacherous character, and the side slopes caved into the excavations.



6.—FRENCH EXCAVATORS AT WORK IN THE EMPERADOR CUT.



7.—THE WORK AT OUTLET OF CULEBRA CUT ON PACIFIC SLOPE.



8.—ROCK CUT AT LA COROSITA, 28 MILES FROM THE ATLANTIC.

THE NEW PANAMA CANAL—CONDITION OF THE WORK IN 1898.

tion faster than the material could be taken out; although now that the cut has reached firmer material this difficulty has disappeared. The hopelessness of the task of building a sea-level canal was by this time apparent, and the company decided to adopt a new plan involving the construction of locks. The decision came too late. The credit of the company was not equal to the raising of further capital, and, in 1889, a receiver was appointed. At this date a sum of \$156,400,000 had been expended upon the isthmus, of which about \$88,600,000 had been put into excavation and embankment. The commission which examined the company's affairs states: "The enormous amount of material at hand ready to be utilized, the great number of works established, lands received, labor actually expended, experience gained, supplies laid in, preliminaries mapped out, including the right of way, are worth to the new company at least \$90,000,000." The receiver obtained at this time a further extension of time to 1904; and a later commission of six years extends the date of completion to the year 1910.

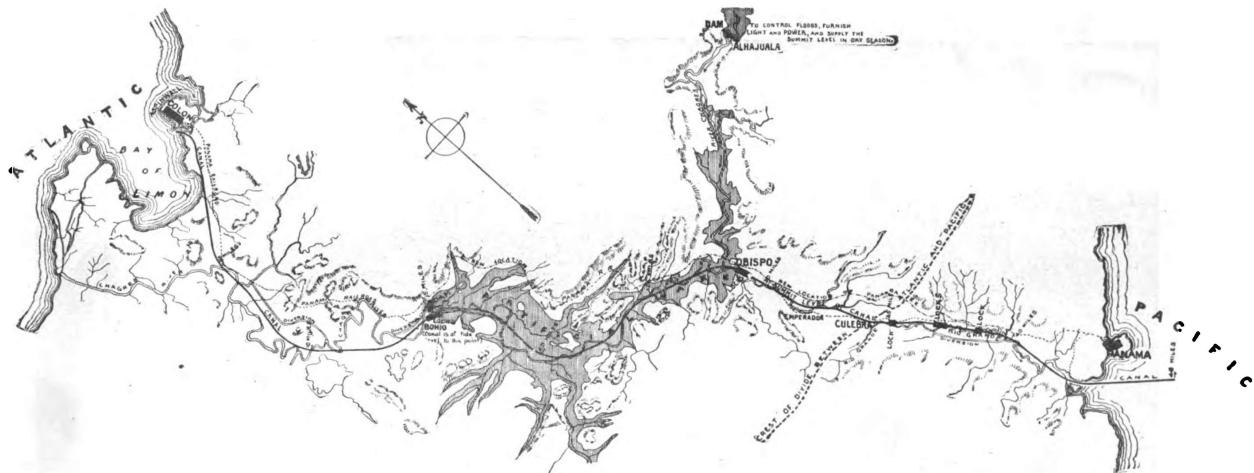
THE NEW PANAMA CANAL.—In October, 1894, a new

force of several thousand men was put upon the work at the more important points, including the great Culebra cut through the divide.

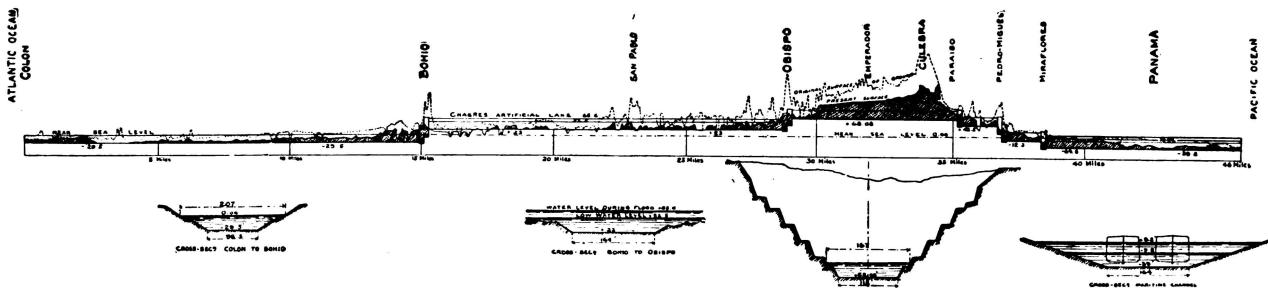
CULEBRA CUT.—The experience of the De Lesseps engineers and the opinion of casual visitors to the Culebra cut had agreed in indicating that the caving in of the loose material would prevent this great ditch from being successfully excavated. The new company accordingly concentrated a large force at this point and at Emperador for the purpose of ascertaining the nature of the underlying material of the mountain. A tunnel 1,100 feet in length was driven along the axis of the canal and a dozen test pits 6 feet in diameter were sunk at various points through the cut down to the proposed level of the bottom of the canal, and the shafts were connected by short tunnels. In short, the mass of material to be excavated was so thoroughly honeycombed in the regions where the worst caving had occurred as to leave no doubt as to its actual composition. Altogether, in the past four years there has been taken out of the Culebra and Emperador cuts 3,924,000 cubic yards of material, and the cost of this survey by excavation has been over \$4,000,000. It

of the Chagres evidently afford an abundant supply, and the problem then took the form of an investigation of the amount of the Chagres River discharge and the possibility of storing it in suitable reservoirs, which should at once serve to feed the summit level and to hold back the rush of the Chagres waters in times of flood. With the question of the Chagres control was associated that of the most desirable elevation of the various locks.

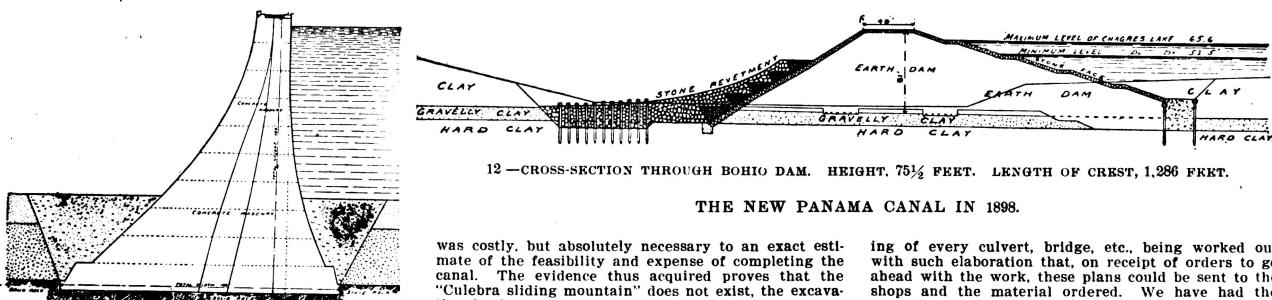
This investigation was intrusted to 150 engineers, who, with their corps of assistants, have been occupied for four years in exhaustive surveys, the total cost of which has amounted to \$1,200,000. This includes, in addition to superintendence of the work at Culebra, extensive borings at the sites of the proposed dams and locks, sufficient to determine the exact nature of the whole site covered by their foundations; gaging of the river; the complete cross-sectioning of the basins of the proposed storage and control reservoirs, together with every kind of research that is necessary to the determination of the feasibility and cost of an engineering work of this magnitude. The investigation has been carried out to the smallest details, the draw-



9.—GENERAL PLAN OF THE NEW PANAMA CANAL.



10.—PROFILE AND CROSS-SECTIONS OF THE NEW PANAMA CANAL.



12.—CROSS-SECTION THROUGH BOHIO DAM. HEIGHT, 75½ FEET. LENGTH OF CREST, 1,286 FEET.

THE NEW PANAMA CANAL IN 1898.

was costly, but absolutely necessary to an exact estimate of the feasibility and expense of completing the canal. The evidence thus acquired proves that the "Culebra sliding mountain" does not exist, the excavation having passed through the upper layer of loose material and reached an argillaceous schist, below which, to the proposed bed of the canal, is solid rock. At Emperador the material is less firm, but perfectly capable of control when provided with proper drainage—a precaution wholly neglected in the happy-go-lucky methods of the De Lesseps regime.

THE CONTROL OF THE RIVER CHAGRES.—Another problem to be solved by the new company was that of the control of the turbulent Chagres River. By reference to the map (Fig. 9), it will be seen that the route of the canal, immediately after passing through the divide at Culebra, follows the course of the Obispo River, a tributary of the Chagres. At Obispo the canal enters the valley through which the latter river flows, and it follows this valley from mile 29 to mile 5, a distance of 24 miles. Now, during the rainy season the Chagres is liable to enormous floods, which were such as to render the canal construction on the original lines a physical impossibility.

The new company decided at the outset to abandon De Lesseps' extravagant idea of a sea-level canal and substitute a system of locks. This decision opened up the question of a sufficient supply of water to compensate for losses and supply the summit level. The floods

of every culvert, bridge, etc., being worked out with such elaboration that, on receipt of orders to go ahead with the work, these plans could be sent to the shops and the material ordered. We have had the pleasure of inspecting the engineering data, and we are free to admit that the plans, profiles, maps, shop drawings, records, etc., are as complete as the most fastidious could ask for.

The new company has evidently laid the lesson of the first failure to heart; but, in order to give further weight to the findings of the engineers, it asked for the appointment of a Technical Commission composed of eminent engineers of different nationalities, whose experience in similar work gave them special qualifications for passing upon the new surveys and plans. The International Commission included such men as Brig.-Gen. H. L. Abbott, Corps of Engineers, U. S. A.; Mr. Fulischer, formerly Engineering Director of the Kiel Canal; Mr. Koch, engineering member of the same canal; Mr. W. Henry Hunter, Chief Engineer of the Manchester Canal Company; Mr. A. Fteley, Chief Engineer Aqueduct Commissioners, New York city; Mr. C. Skalkowski, formerly Director of Mines, Russia; and four of the former General Inspectors of Roads and Bridges, France.

This commission, organized in 1896, through some of its members has made personal inspection of the canal on the isthmus and in addition to having at its disposal the local records of rainfall and floods for the last 15

11.—CROSS-SECTION THROUGH ALHAJUELA DAM. HEIGHT, 164 FEET. BASE, 166 FEET. LENGTH OF CREST, 936.7 FEET.

company was formed for the purpose of completing the canal. It was organized with a cash capital of \$13,000,000, and, with a view to giving it a commanding position in the financial world, the stock was purchased by several of the leading financial institutions in France, the whole \$13,000,000 being actually paid in. The new company was officially recognized and its titles, etc., duly confirmed by the Colombian government.

On coming into possession, the new owners very properly determined that their first duty was to make that complete study of the engineering features of the scheme, to the lack of which the failure of the old company was largely due. They also determined to begin work on a considerable scale with a view to determining exactly what quality of material would be encountered in completing the excavations and building the various dams and locks. To this end a staff of one hundred and fifty engineers was placed in the field and

years, for two years has made its own elaborate records of rainfall and of the flow and floods of the Chagres, and has held over 100 sessions. It presented a unanimous report on December 2, 1898, which, considering the standing and experience of the members, is perhaps the most representative and authoritative document of the kind ever drawn up.

The report fully endorses the plans and estimates of cost of the new canal.

THE NEW PANAMA CANAL.—The International Commission find that the work on the canal is at present two-fifths completed, that the cost to complete the work under the new plans will be \$87,000,000. If 20 per cent be added for contingencies, the total cost is \$102,400,000, and the time for completion, not allowing for improvements in methods of working and plant, is from eight to ten years.

The canal is forty-six miles in length. The map (Fig. 9) shows its location, and the profile (Fig. 10) shows by a dotted line the amount of excavation that has been done and by a full line and shaded portions, the excavation remaining to be done. The engineers drew up three designs for a canal with locks. In the first the summit level was to be 96 $\frac{3}{4}$ feet; in the second, 68.08 feet; and in the third, 32 $\frac{1}{2}$ feet above the

upon solid rock, and will consist of concrete masonry. Its crest, 936.75 feet long, will be 134 feet above the river bed and 164 feet above the lowest foundation.

This dam will be connected with the summit level by a feeder with a capacity of 6,605 gallons per second. The dam will also furnish energy for the electric lighting of the canal and the electric operation of the locks, etc.

The storage capacity of the two artificial lakes thus formed will be 66 billion gallons, which provides a wide margin of safety, as shown by careful records, over any possible flood discharges of the river. The records of the flow of the upper Chagres have demonstrated that the surplus quantity of water impounded during the rainy season by the Alhajuela dam will be many times as great as will be necessary to supply the summit level during the dry season.

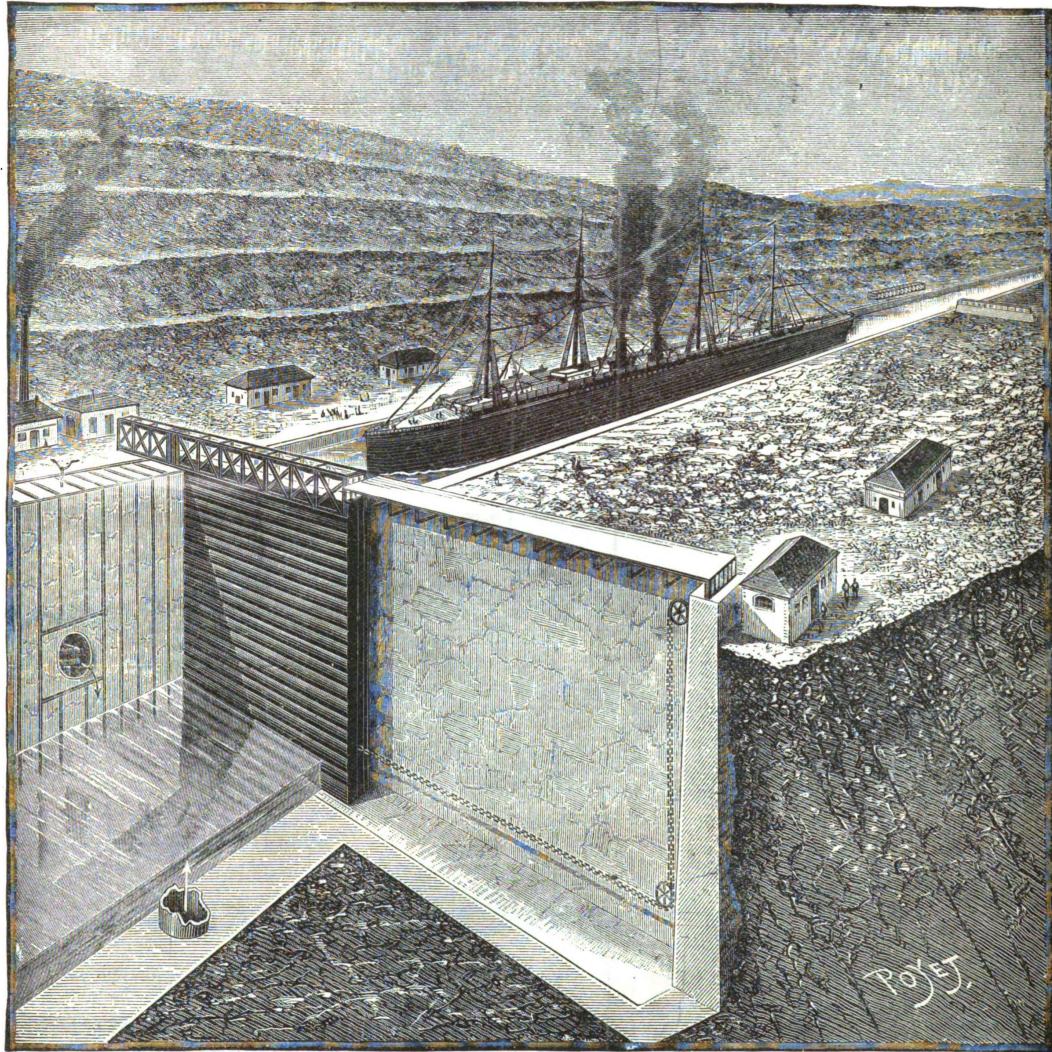
Commencing at Colon on the Atlantic, the first section of the canal, 15 miles in length, is tidal up to the two double locks at Bohio, by which vessels will pass into the Chagres River lake. These locks are of masonry and will be built upon rock foundations, as will all the locks of the canal. The deep cut shown in Fig. 3 is the site of the Bohio locks. The Obispo dam will be half a mile to the left of the locks in the bend of the

ticularly in the Culebra cut, are to be reveted with stone, and that the curvature of the canal is easy throughout, the smallest radius being 8,200 feet and the prevailing radius 9,842 feet.

THE QUESTION OF HEALTH.—The Technical Commission examined carefully into the question of mortality and concluded that the climatic dangers have been exaggerated. It is true, during the first years of operation, owing to carelessness as to sanitation, the employment of races not used to hard labor in the tropics, and the fact that surface ground full of fever germs was being opened, the loss of life was serious. Of late years, however, owing to the employment of negroes from the British Antilles who are used to the climatic conditions, and as a result of the fact that the excavation is in the deeper rock formations, the amount of sickness is not abnormal.

THE NICARAGUA CANAL.

THE question of an Isthmian canal is one of site, practicability, and cost. Beyond demanding that the canal as completed shall be the cheapest and best that can be built and shall secure to the United States every advantage to which it is justly entitled of a com-



SLIDING LOCKS OF THE PANAMA CANAL—DESIGNED BY EIFFEL FOR CANAL WITH LOCKS.—DATE, 1888.

sea level. The technical commission recommends the second, which is the one shown in the map and profile.

As the determination of the levels and number of locks is dependent upon the means taken to control and utilize the Chagres River, it will be well to explain that this control is secured by constructing two large dams, one at Alhajuela, in the upper Chagres, about nine and one-third miles above the canal (see map), and the other at Bohio, at the end of the sea level length of the canal on the Atlantic side. The Bohio dam will be thrown across the Chagres valley at a point about half a mile to the left of the canal at Obispo. It will be of earth, upon a bed of compact clay. The general features are shown in the cross-section, Fig. 12. The crest is 1,286 feet long, and the extreme height above the bed of the river is 75 $\frac{1}{4}$ feet, and above the foundation 93 $\frac{1}{2}$ feet. This dam will create a vast artificial lake, which will extend thirteen and a half miles to Obispo. Its lowest level will be 52.5 feet and its highest level, when the river is in flood, 65.5 feet. The channel of the canal will lie in the bed of this lake, which will not only take care of a large part of the flood waters, but will greatly reduce the amount of excavation necessary for the canal. The other dam, at Alhajuela, will be built everywhere

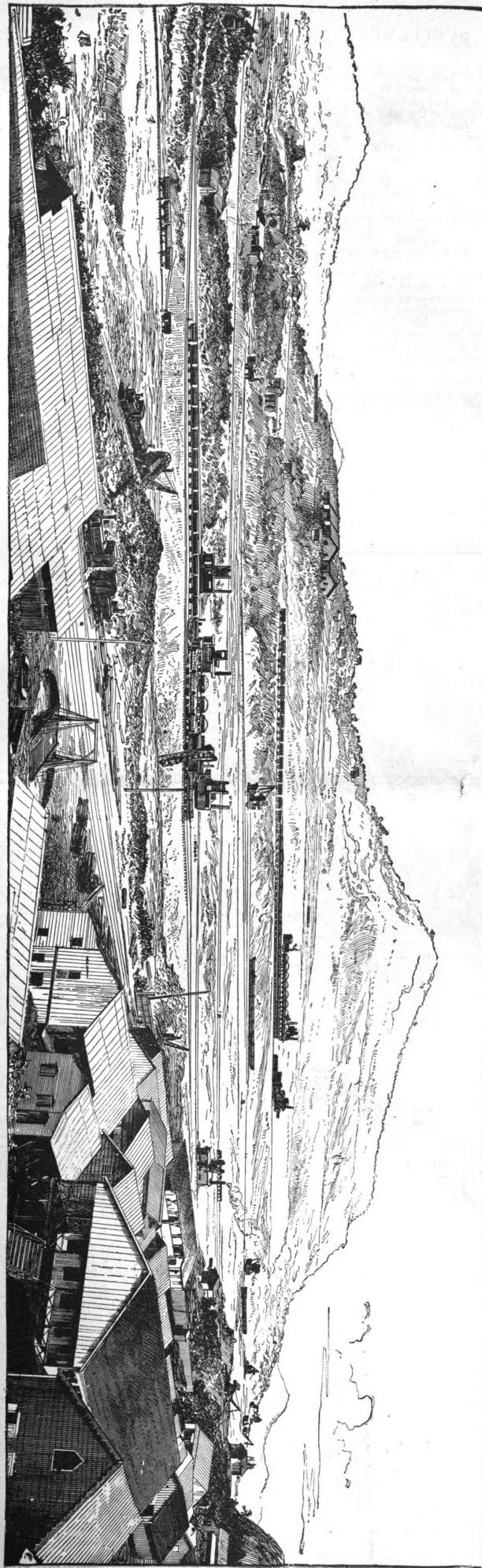
the Chagres River, which river is seen in the foreground of this same illustration. The working length of the locks will be 738.22 feet, the width of one of the twin locks being 82.02 feet and of the other 59.05 feet. Of this sea level stretch of the canal, the first 11.8 miles are navigable, the depth varying from 16.4 feet to 29.5 feet, the finished depth. It has been excavated to the original width (see Fig. 5), and not much dredging will be necessary to complete it for the whole 15 miles to Bohio. After passing the locks the canal channel extends for about 13 $\frac{1}{4}$ miles along the bed of the lake to Obispo, where two double locks (built like all the other locks of the company upon a rock foundation) will admit vessels to the summit level 5 miles in length, where the bottom of the canal is 68.08 feet above mean sea level. On the Pacific slope admission is gained at Paraíso by one double lock to a level 7,963 feet in length, and at Pedro-Miguel two double locks lead down to a level 7,930 feet long, from which at Miraflores one double lock will admit vessels to the tide level of the Pacific. This portion of the canal is 7 $\frac{1}{2}$ miles in length. The depth of water in the locks will be 29.5 feet and will not exceed 32.8 feet.

It should be noticed that the slopes of the canal, par-

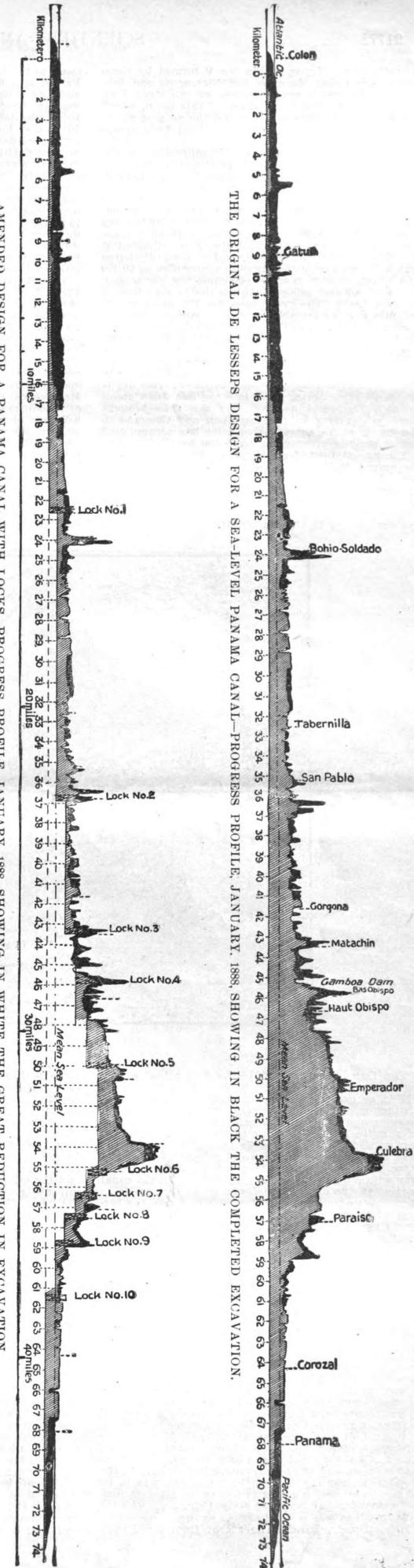
cial, strategic and political character, we believe the public is indifferent as to whether the canal is cut through at Panama, Nicaragua or elsewhere.

Probably there is no question involving such an enormous outlay of the public money upon which the people of the United States are so little informed as they are upon the relative standing and merits of the two proposed canals. This and the preceding article were written with a view to giving such an impartial statement of the facts as shall enable the reader to judge for himself of the relative merits and demerits of the rival schemes.

A glance at any map and profile of the proposed route of the Nicaragua Canal is sufficient to explain why it is that from the earliest times it has attracted attention as affording a feasible means of ship communication across the isthmus. The mountain range known as the Cordilleras, which forms the divide between the drainage of the Atlantic and Pacific, separates at a point about 70 miles north of Lake Nicaragua into two branches, one of which extends in a southerly direction between the lake and the Pacific, while the eastern divide runs parallel with and some 18 miles to the east of the lake and then in a southerly direction until it terminates near Greytown on the



THE GREAT CULEBRA CUT THROUGH THE DIVIDE IN 1888.



AMENDED DESIGN FOR A PANAMA CANAL WITH LOCKS—PROGRESS PROFILE, JANUARY, 1888, SHOWING IN WHITE THE GREAT REDUCTION IN EXCAVATION.

Atlantic coast. Lying within the V formed by these ranges are Lakes Managua and Nicaragua, and into these lakes, which are connected by the river Tipitapa, there empties the drainage of this basin, which has an area of 12,000 square miles, the area of Nicaragua being somewhere between 2,700 and 3,000 square miles.

The lake is 45 miles wide by 110 miles long, and it extends in a general southeasterly direction, its longer axis being parallel with the Pacific Ocean, which at the nearest point is only 11 miles distant. The lake is for the most part deep, and its waters have a mean surface level of 106 feet above sea level. The only outlet for the waters of the lake is by the way of the San Juan, a noble stream of great volume with an average width of 1,500 feet, a minimum discharge estimated at 12,000 cubic feet per second, and a flood discharge which has been estimated by some authorities as 60,000 and by others as high as 150,000 cubic feet per second, the latter amount being two-thirds the average flow of Niagara itself. The river flows for 120 miles to the Atlantic and is navigable for river steamers, except at some rapids, which in the dry season offer obstruction. On the north side but a few streams flow into the San Juan, but the streams that enter it from the south are large and subject to heavy floods which carry down immense volumes of sand from the Costa Rican range some 50 miles distant. The most turbulent tributary is the San Carlos, which flows into the San Juan above Ochoa. The sand and volcanic ash thus brought down are carried by the San Juan and Colorado to the coast, where an extensive delta has accumulated and is steadily encroaching upon the sea.

The navigability of the San Juan and the lake, and the narrow divide separating the lake from the Pacific, have, from very early times, suggested the possibility of opening a ship canal across the isthmus at this point, and surveys of a general and preliminary character looking to this object were made as long ago as the close of the eighteenth century.

coast to the lake was to be by way of the Rio Grande Valley, and by means of 11 locks of $10\frac{1}{2}$ feet lift, and the canal was to be cut directly through the western divide to the lake. This portion was to be $16\frac{1}{4}$ miles long. The route across the lake was to be $56\frac{1}{2}$ miles long. The San Juan was to be navigated by placing dams in the river at four places, the uppermost at Castillo, the lowest a mile below the mouth of the San Carlos. This river portion was to be $66\frac{1}{2}$ miles long. At the lowest dam the canal was to leave the river, follow its left bank to the San Juanillo, and then proceed by a straight course to Greytown. The total length of the canal from ocean to ocean was to be $181\frac{1}{4}$ miles. As Greytown Harbor had been silted up since the Childs survey, an estimate of \$2,500,000 was made for its restoration. The total cost of the project, including 25 per cent for contingencies, was estimated at \$65,722,147.

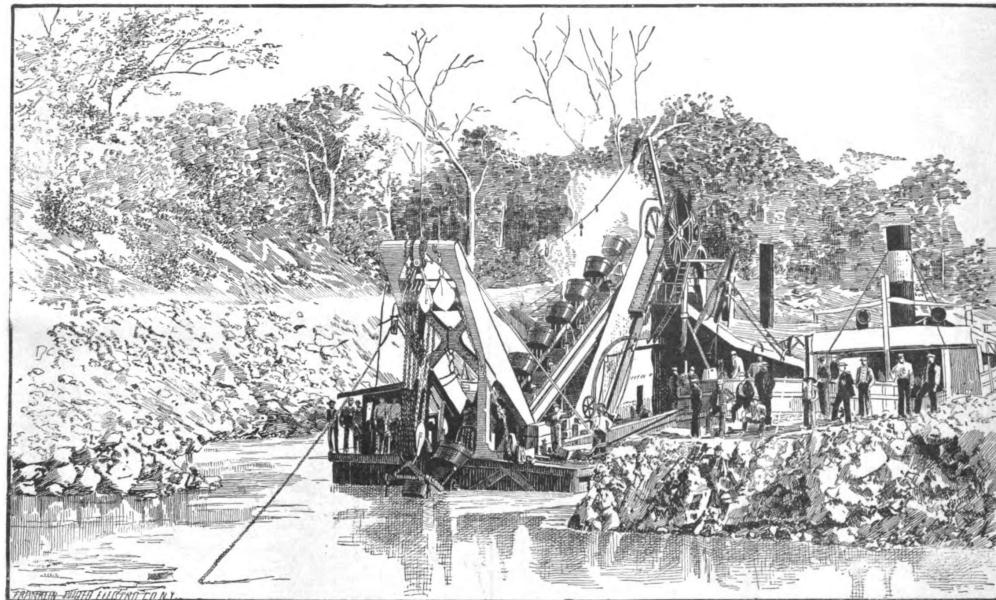
THE MARITIME CANAL COMPANY'S SURVEY, 1887 TO 1890.—The next step was taken in 1885, when Mr. Menocal was directed by the government to make a re-examination of the work, and estimate for the construction of a 28-foot canal. In his report of that year he recommended some very radical changes in the Lull plan and outlined a project which involved some bold engineering measures, especially in the canalization of the San Juan River. The total estimate for the canal was \$60,036,197. Four years later Mr. Menocal returned to the isthmus as chief engineer of a company (the Maritime Canal Company), which had been formed for the purpose of building the canal on the general lines proposed by him in the 1885 report. A large engineering force was put in the field between the years 1887 and 1890, and in the latter year a report was presented by Mr. Menocal and elaborated in the Chicago Waterways Congress of 1895, setting forth the data and plans upon which it was proposed to build the canal.

It is admitted by the many expert engineers who have criticised the Menocal project that if it were pos-

sible, known as the San Francisco and Deseado basins, connected by short lengths of canal. Lock 3 is only 13 miles from the Atlantic (Caribbean Sea), so that by this original and daring proposal the summit level would be extended continuously for 154 miles across the isthmus, its eastern terminus being within 13 miles and its western terminus within two miles of the respective oceans. On both sides descent was to be made to sea level by three locks. At the Pacific level the lowest lock would be within a mile of the deep water and on the Atlantic it would be necessary to dredge a canal 9.4 miles in length through the alluvial deposits of the river.

CONSTRUCTION OF DAMS.—Now, to construct a dam 60 to 80 feet high across a great river whose waters in time of flood may be over one-half as great in volume as the flow of Niagara is a stupendous undertaking. Mr. Menocal evidently realized that it was hopeless to divert the river, lay bare its bed, expose the underlying rock, and build up an impervious dam in the ordinary way, for he proposed to make a high, loose-rock fill across the river, dumping in the material excavated from the big cut through the eastern divide in as large blocks as possible. The rock, of which the cut would afford an abundant supply, was to be dumped in until it had ceased to sink into the soft bed of the river and a stable structure had been secured. To render it impervious, the excavated clay from the neighborhood was to be dumped upon the upstream face of the dam. A similar method of construction was to be used for the numerous embankments of the San Francisco and other streams crossed by the canal, and for La Flor dam. The most startling proposal of all, however, was that to use the rock-fill dams as weirs over which the surplus waters of the lake and rivers were to discharge.

HARBORS.—All the surveys that have been made for a canal have realized the necessity of creating terminal harbors at each seaboard. On the Pacific the canal terminates at Brito, an indentation of the coast,



EXCAVATING PLANT AT PANAMA—FRENCH DREDGE.

THE CHILDS SURVEY, 1852.—The first actual survey for a canal was that made in 1850-52 by Col. O. M. Childs, an expert canal and railway engineer of great distinction, for the Transit Company, which had a steamer and stage line across the isthmus as part of a route from New York to California. Steamers ran up the San Juan from Greytown to California and crossed the lake to its west coast, where they connected with a stage line to the Pacific. The survey was for a waterway with a depth throughout of 17 feet. In the canal portion the bottom width was to be 50 feet, while in the excavated channels in the river and lake the bottom width was to be 150 feet. Locks were to be 250 by 60 by 17 feet. Ships were to pass from the sea level on each side of the summit lake level of 108 feet by 14 locks, each with an 8-foot lift. The lake was to be held at 108 feet elevation by a dam in the Rio Grande Valley $9\frac{1}{2}$ miles west of the lake and another at Castillo Rapids $37\frac{1}{4}$ miles east of the lake in the San Juan River. The lowest lock on the east side was to be at point 90 miles from the lake, where the canal was to leave the river and extend across the flat alluvial land to Greytown, where at that time there was a well-protected harbor. The total length of the Childs canal was to have been 194.4 miles, and its cost, including 15 per cent for contingencies, was estimated at \$31,538,319.

THE LULL SURVEY, 1873.—The United States government sent an expedition to the isthmus in 1872 under Commander Lull, U. S. N. for the purpose of making a resurvey of the Childs route. With Commander Lull was associated Mr. A. G. Menocal, the present engineer of the Maritime Canal Company. The depth of the canal was to be 26 feet and its bottom width 50, 60, and 72 feet, according to locality. In the excavated river channel the bottom width was to be 80 feet and something over 80 feet in the lake channel.

Commander Lull proposed several changes. The Pacific terminus was to be the same as that proposed by Childs, namely, Brito. The ascent from the Pacific

sible to eliminate from it certain elements of danger, it would provide a canal which would be in every way superior to the other alternative plans which have been submitted. Its most striking feature was that it proposed to extend the summit level of 110 feet almost from ocean to ocean. This was to be done by the construction of two great dams, one at La Flor on the Pacific slope of the western divide, at a narrow gorge in the Rio Grande Valley, 3.8 miles from the Pacific, and the other at Ochoa, a point on the San Juan, $3\frac{1}{2}$ miles below the San Carlos River and $64\frac{1}{2}$ miles from the lake. The Ochoa dam would rise 60 feet above the water surface of the San Juan at that point and would cause its waters and those of the San Carlos to back up and flood the two valleys, converting them into lakes which would actually form extensions of the Nicaragua Lake itself. An important feature of the design was the use of the San Carlos Lake as a settling basin for detritus brought down from the mountains. La Flor dam on the Pacific, being placed below the mouth of the Tola, a tributary of the Rio Grande, would similarly flood the Tola Valley, converting it into another lake at the level of and forming part of the big lake.

Nor was this all. With a view to shortening the route and still further extending the summit level, Mr. Menocal proposed to proceed to Greytown, not, as Lull and Childs advised, by way of the marshy lowlands through which the San Juan finds its way to the sea, but by a direct route across the intervening ridges and valleys, and through the crest of the eastern divide. To do this he proposed to raise embankments across the lower side of the valleys and make cuttings through the intervening ridges, and allow the San Juan waters to flood the basins thus formed, the embankments being built to the same height as the Ochoa dam and serving to maintain the summit level right through the eastern divide and up to lock number 3 (see profile). The portion between the Ochoa dam and lock 3 would thus consist of two large artificial

while at the Atlantic it ends on the shifting sands which have silted up what was once the deep-water harbor of Greytown. At Brito both Childs and Lull estimated that a new harbor would cost about two and one-half million dollars, while the Maritime Company's estimate put it at about one and three-quarters million dollars. It was proposed to create the harbor by running out projecting jetties and dredging out an interior basin. The construction presents no problems that are novel or untried in engineering practice. At Greytown, however, as a study of the accompanying map will show, the problem will require careful study, and after the harbor is complete will call for continual dredging and successive additions to the jetty. To understand the conditions we must bear in mind two things: First, that for ten months of the year the trade winds and seas move upon the beach from the northeast; second, that enormous masses of volcanic silt are brought down by the San Juan and deposited, through the Colorado branch, at its mouth, to the eastward of the harbor. The waves, striking this material at an angle with the coast, transport it to the westward to the amount, as estimated by the present Walker Board, of 600,000 cubic yards per year. This remarkable drift is seen in the map of the Peacock survey of 1832, in which the westward travel of the sand is shown from 1832 to 1859. The progress of the sand silt has been accompanied by a shoaling up of the harbor until in 1859 the once capacious harbor with its low water depth of 30 feet has shrunk to a mere lagoon with a maximum depth of 17 feet. To open a channel from the canal to deep water the company built a pile and rock jetty 900 feet in length. This was done for the purpose of arresting the westerly drift and enabling them to dredge a channel on its western side. The sand accumulated on the eastern side of the jetty, reached the outer end, flowed past it, and formed the curious tongue which is seen extending past the jetty and almost across the entrance channel. This result shows that while it will be possible to obtain an em-

trance by extending the jetty far out to deep water, the filling in of the beach behind it at the rate of 600,000 cubic yards per year will be perpetual, and the jetty will require to be extended at recurrent intervals. As there is no tidal scour to rely upon, the channel will have to be maintained by the use of dredges. The company's proposition was to build an east pier 3,000 feet long, and a west pier about 2,000 feet in length, with an entrance 600 feet in width. The entrance channel, 5,000 feet long, was to connect with an artificial basin 237 acres in extent, dredged out at the Greytown Lagoon to a low water depth of 30 feet. The total cost of the whole scheme, including the harbors, was estimated by the company at \$65,084,176.

WORK DONE BY THE COMPANY.—A start in construction was made by the company at the Greytown end. Five large dredges commenced cutting through the alluvial deposits through which the first 9 miles of the canal will be cut. Some 4,500 feet of the canal were cut to a depth of 16½ feet and the canal line through the dense tropical growth was cleared for a distance of 32 miles. A single track railroad was built from Greytown, 11 miles into the interior. The jetty above mentioned was built out 900 feet, and a 17-foot channel dredged from the sea to the Greytown Lagoon.

THE LUDLOW COMMISSION.—The operation of the canal company ceased in 1893 for lack of funds. In 1892 the Senate Committee on Foreign Relations introduced a bill providing for the aid of the United States in the construction of the canal by a guarantee of the bonds issued for construction, and in 1895 Congress appointed a commission consisting of three well known engineers, Colonel Ludlow of the army, Civil Engineer M. T. Endicott, of the navy, and Alfred Noble, a civilian in private practice, for the purpose of reporting on the "feasibility and cost of completion" of the company's project. After examining the route on the isthmus and the engineering data collected

sonal examination of the route and placed in the field a well-equipped force of 250 men, including 80 engineers, a geologist, a hydrographer, ten boring outfits, and a very complete set of apparatus for determining rainfall, evaporation, flow of streams, and all the natural phenomena affecting the construction and maintenance of the canal. The expedition landed in December, 1897, and the observations, plans and estimates are still in progress, and will not be fully completed for some time.

At a preliminary hearing before a select committee of the Senate the members of the commission roughly estimated the cost of construction as follows: Admiral Walker, \$125,000,000; Prof. Haupt, \$90,000,000; and Gen. Hains, \$140,000,000. In a preliminary report, issued at the close of last December, the commission states that of all the routes that have come up for consideration, the two best are the Maritime Canal Company's route, known as the high level route, and the Lull or low level route. The estimated cost is \$124,000,000 for the latter and \$125,000,000 for the former. Gen. Hains, however, who is the oldest and most experienced member of the commission, states in a supplemental note to the report that he thinks the estimate should be raised to about \$150,000,000.

All these members of the commission "believe that the construction of the canal across Nicaragua is entirely feasible."

RECOMMENDATIONS OF THE WALKER COMMISSION.—Although some time must elapse before the final report is made public, we are in a position to state what will be the general features of the plan finally recommended by the commission. In the first place, the Ochoa dam will be moved up the river to a point above the San Carlos, with a view to eliminating the torrential floods and the silt of that river, which will be allowed to pass away in the ordinary manner through the San Juan.

No attempt will be made to hold the summit level up

the rainfall is excessive (22 feet on the eastern section), the material will stand up remarkably well in excavation. Moreover, the climate, on account of the prevailing trade winds, is not unhealthy, and it is not apprehended that it would prove a hindrance to the prosecution of the work. The estimated time for completion is from eight to ten years.

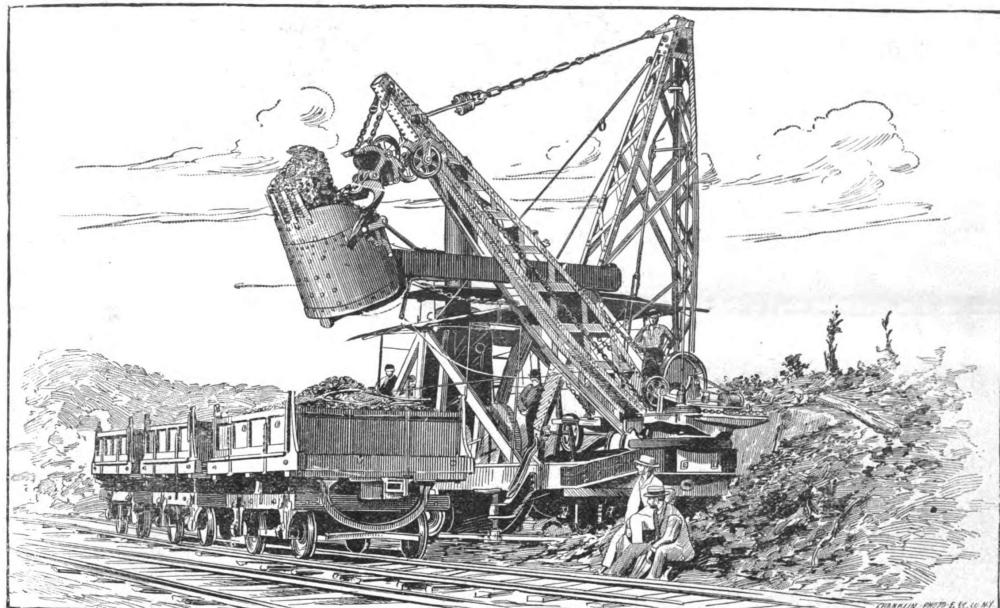
REPORT OF THE Isthmian Canal Commission.

The report of the Isthmian Canal Commission is the record of by far the most costly and complete investigation of the Isthmian Canal problem ever carried out. The Commission is made up of some of the most eminent engineers in army and civil life; it has spent three years of time and over one million dollars of money in examining the Panama, the Nicaragua and every other possible route across the Isthmus; it has visited every canal of importance in Europe; under its direction thirty-one engineering parties have been employed in a survey of the isthmus as follows: 150 engineers and assistants at Nicaragua, 20 engineers and assistants at Panama, 50 engineers and assistants at Darien.

The report says that a tide level canal at Darien would involve a 4.2-mile tunnel, and would cost \$289,770,000, while canals on three alternative routes at Caledonia, would cost from \$263,340,000 to \$320,040,000. Dismissing these as financially impracticable, the report discusses the Panama and Nicaragua routes in very elaborate details. A digest of this portion of the report follows:

THE PANAMA ROUTE.

The natural attractions of the Panama route lie in the combination of a very narrow isthmus with a low summit. The width of the isthmus is less than 36 miles in a straight line, only 5 miles more than at San Blas, the narrowest place, while the original summit



EXCAVATING PLANT AT PANAMA—OSGOOD AMERICAN EXCAVATOR.

by the company, the commission reported that while a ship canal project was feasible, they were unable to indorse several important features of the company's plans. They considered that the data upon which the plans were drawn up was neither sufficiently detailed nor spread over a sufficient period of time to enable accurate conclusions to be drawn, either as to permanence of the proposed structures or the cost of the undertaking as a whole. They considered that the quantities of dredging, excavation, etc., were underestimated, and that the unit prices had been placed too low. They raised the quantities and prices accordingly, and made an estimate of their own which placed the probable cost of completion at \$133,472,893, as against the company's estimate of about \$67,000,000, an increase of 100 per cent.

The features most severely criticised by the commission were the two great rock-fill dams at each end of the summit level, one at La Flor, 2,000 feet long and 90 feet above the bed of the river, the other at Ochoa, 1,900 feet long and 60 feet above the river bed, and the extension of the canal through the San Francisco basin, where it would be necessary to construct 67 clay dams or retaining embankments, one of which is 1½ miles in length, and rises 100 feet above the foundations. It was also stated by the board that they found indications of an extreme variation in the level of the lake in wet and dry seasons of 15 feet, and that this variation, extending over an area of nearly 3,000 square miles, represented an enormous volume of water, which it might prove extremely difficult to hold at the desired elevation of 110 feet.

The board suggested that a more thorough examination of the locality might disclose alternative routes which would be free from the objections outlined in their report, and they suggested that \$350,000 should be appropriated for a further examination to finish the investigation and prepare final plans and estimates. This recommendation was acted upon, and a new commission consisting of Admiral Walker, Prof. Lewis M. Haupt, and Gen. Hains spent three months in a per-

manent camp on the Ochoa dam; but an intermediate dam and a lock will be placed at one of the upper rapids—probably Machuca—and the level will be lowered 20 or 30 feet at that point. This will reduce the height of the Ochoa dam by nearly one-half, and the canal will be carried from Ochoa down the left bank of the San Juan to a point at which it will strike off across the divide in the same manner as, but at a lower level than that proposed in the Menocal scheme. This will increase the cuts but reduce the heights of the embankments, thereby avoiding the risky features of the high level route. This route will be in the nature of a compromise between the high level route of the company and the low level route located by Lull.

The security of the Ochoa dam is further assured by the discovery of solid rock everywhere underlying the bed of the river at the proposed site, and a firm clay has been developed along the site of the embankment foundations. The Menocal idea of using the dams as overflow weirs has been abandoned; separate weirs will be placed in every case.

The commission finds that it can regulate the level of the lake within a recorded fluctuation of 2½ feet above and below the normal. On the west side of the lake, La Flor dam and Tola basin are abandoned. The canal will be cut through the divide to the Rio Grande, and it will be carried down to sea level at Brito by means of locks whose number has not been determined. To assist in controlling the lake level and relieving the duty thrown upon the San Juan, it is not unlikely that the canal through the western divide will be given considerably greater width to enable it to assist in carrying off the surplus waters in the seasons of flood.

The least depth throughout of the canal will be 30 feet. All excavated channels will be given extra width both in the river and lake, while the curvature will be eased to render navigation less difficult. All locks will be of a length and depth to accommodate the increased dimensions of modern steamships.

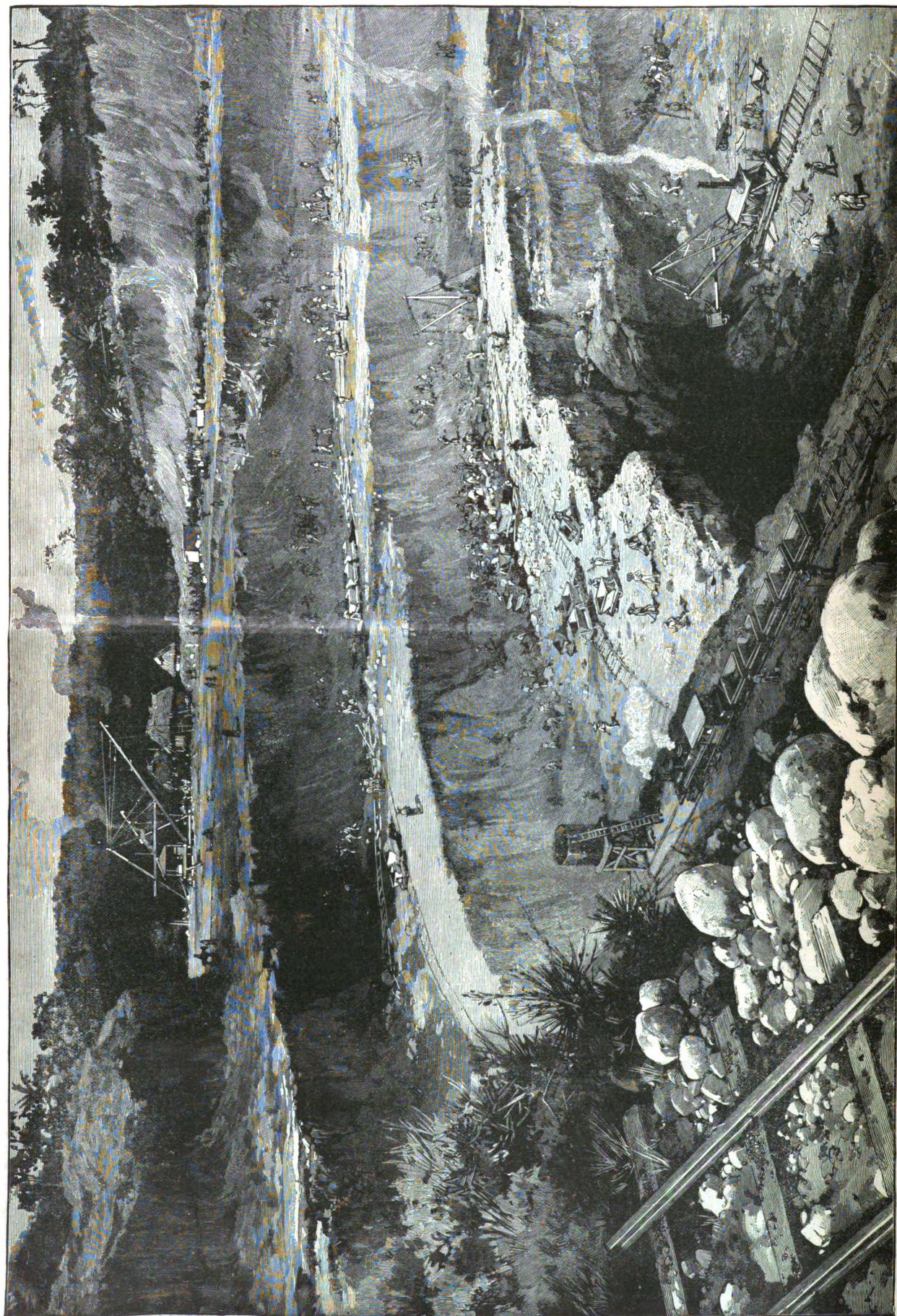
Finally, the commission is of the opinion that while

was less than 300 feet above tide water, which, though higher than the Nicaragua summit, is less than half the height of any other summit which has been investigated. Furthermore, the high portion of the isthmus is limited to a width of about 6 miles near the Pacific side, and the Chagres River affords canoe navigation from the Atlantic to within 16 miles of the Pacific.

The isthmus here runs nearly east and west, but the course of the railroad or canal is from northwest to southeast, the Pacific terminus being about 22 miles farther east than the Atlantic terminus. The Atlantic port is Colon, and the Pacific port Panama. At Colon the mean tidal range is about 1 foot; at Panama it is about 20 feet. The harbors are not of the first class. They have served the demands of a limited commerce heretofore. Some improvements at Colon would be necessary if the canal should be built. The defect of the Colon Harbor is that it is exposed to "northerns." When these are severe, ships are now compelled to go to sea. This may occur once or more each year. Panama Harbor is a roadstead behind islands at the head of a great bay or gulf. For the terminus of a canal it is sufficient, as the stay of vessels is expected to be short.

PHYSICAL DATA AVAILABLE.

The old Panama Canal Company began its work without adequate knowledge of the physical conditions at the isthmus. It inaugurated at an early day some of the surveys and examinations required to supply the deficiency, and some of these it maintained as long as it continued to exist. Additional surveys were made by the liquidator, and very extended additional surveys and observations have been made by the new company. The information relating to the topography, hydrography, and geology of the isthmus is now much more complete than is usual before inauguration of an engineering enterprise in a new country. The canal company spared no trouble or expense in laying it all before the Commission. The most important maps, drawings, and documents were lithographed or printed and systematically arranged for the use of the Commiss-



sion, copies being furnished for each member. Many other documents were supplied in manuscript. In all some 340 documents, many of them elaborate studies, were furnished. These supplied essentially all the data required for the preparation of plans and estimates, though further information was desired as to the foundation upon which the great dam at Bohio must be built, and as to the area of the Chagres River drainage basin. This additional information was obtained by the field parties of this Commission. It was necessary also for the purpose of this investigation to verify the French data. Independent lines of levels, measurements of distances, borings, soundings, and hydrographic observations made by its own parties, supplemented by personal observation, enable this Commission to state that the data furnished by the canal company are essentially correct.

LAKE BOHIO.

No location suitable for a dam exists on the Chagres River below Bohio, and while this location is not without difficulties it has the great advantage that about 3 miles southwest of the dam, near the head of the Rio Gigante, a tributary of the Chagres, there exists an excellent site for a spillway, by which the discharge from the lake can be kept well away from the dam and accessory works, and may be made extremely large without inconvenience either to the canal itself or to the country below the lake. The height of this spillway would regulate the height and area of the lake. After careful consideration of the requirements for flood control and for storage against deficiency in the dry season, and also of the effect upon the amount of excavation required for the canal through the continental divide, the Commission has decided to fix this height at 85 feet above mean tide, and to make the spillway a fixed weir 2,000 feet long. The area of the lake at this height is 38.5 square miles, or 1,073,318,400 square feet. Using coefficient 3.5 in the weir formula, it is computed that with a depth of 5 feet over its crest the weir will discharge 78,260 cubic feet per second. In reaching elevation 90 the area of the lake will be enlarged to about 43 square miles and it will impound over 5,680,000,000 cubic feet of water. The quantity of water discharged over the weir while the lake is rising from elevation 85 to elevation 90, assuming circumstances of flow similar to those observed in the flood of 1893, is computed to be about 4,000,000,000 cubic feet. The total quantity of water impounded and discharged before the lake will rise above elevation 90 is therefore nearly 10,000,000,000 cubic feet. It provides for unimpeded navigation during all floods not exceeding 75,000 cubic feet per second. The velocity of the currents in the narrowest part of the lake would not exceed 2 feet per second. Floods may occur, however, which will cause the lake to rise above elevation 90. From the data available it is not possible to compute with precision the exact height which a flood may hereafter attain, but the extreme possible effect of a flood discharging 140,000 cubic feet per second for a prolonged period would be to raise the water over the spillway to 92.5 feet. All great floods are of short duration, and such a flood is absolutely without precedent, being as improbable as any other convulsion of nature. The crest of the dam has, however, been placed at 100 and the top of the lock walls and gates at 94, to make them entirely safe from overflow by even such a flood, the ill effect of which would be limited to the temporary obstruction of navigation by swift currents in the narrowest part of the lake, where the velocity might reach 5 feet per second. Under extreme conditions the lake might be lowered to 82 to provide water for operating the canal during the dry months. The excavations will be so adjusted as to give a depth of 35 feet at that level. This provision for the storage of water for use in the dry season is ample for a traffic of 10,000,000 tons per annum in vessels of the size now in common use. It will be equally ample for a much larger tonnage if, as seems probable, the size of vessels continues to increase. For example, the number of vessels which passed the Suez Canal in 1900 was 3,441, against 2,389 in 1890, while the gross tonnage in 1900 was 13,699,238, against 9,749,129 in 1890. The number of vessels in 1900 was less than in 1898, while the total tonnage was greater. The annual flow of the Chagres and the topography of the country are favorable, however, to a very large increase of the supply, if that be found desirable in the future. A reservoir can be constructed at Alhajuela with a capacity for storing an additional volume of water four times that now provided for daily consumption.

The overflow of Lake Bohio will discharge through the Gigante spillway into Pena Blanca Swamp, thence through natural and artificial channels to the Chagres River below Gatun, and thence through that river to the sea, being kept out of the canal in the lowlands by levees where necessary.

DETAILED DESCRIPTION.

The canal, as thus projected, may be described as follows:

Beginning at the 6 fathoms line in Limon Bay, a channel 500 feet wide at bottom, and with side slopes of 1 on 3, is excavated, curving gently to the left upon a radius of 6,560 feet, until it reaches a point just inside the jetty constructed by the old Panama Canal Company. Here it changes direction to the right upon a curve of 3,280 feet radius, and is then conducted upon a straight line for a distance of 2,000 feet to a point 2.39 miles from deep water in the bay. For about a mile this wide channel is inside the shore line, forming a narrow but well-protected harbor. Near the apex of the second curve the bottom width is increased to 800 feet for a length of 800 feet, to provide a turning basin.

COLON TO BOHIO.

From the inner end of the harbor the bottom width of the canal is 150 feet, the side slopes of 1 on 3 being retained for 1.86 miles through the swamp, after which they are reduced to the standard used in firm earth, and are kept at that standard for a distance of 12.56 miles farther to the Bohio locks. The length of this line measured from the inner end of the harbor is 14.42 miles.

BOHIO LOCKS.

At Bohio is located a double flight of locks, having a

total lift varying from 82 feet at the minimum level of the lake to 90 feet at the maximum, 41 to 45 to each lock, the normal lift being 85 feet. These locks are on the location adopted by the French company. They are of the type adopted for both the Nicaragua and Panama canals and described elsewhere in this report.

LAKE BOHIO.

Above the locks the canal enters the artificial lake formed by the Bohio dam and known as Lake Bohio. For the first 7 miles it is a broad, deep body of water, affording room for anchorage, as well as navigation. Beyond this some light excavations are necessary. At the upper end the channel will be enlarged to provide for the flood discharge of the Chagres, being given a minimum section of 42,000 square feet. The length of the channel in Lake Bohio is 12.68 miles from the locks to the point where the canal leaves the Chagres. The section extends ninety-three hundredths of a mile farther, to the point where it enters the cut through the divide.

OBISPO GUARD GATES.

Near the entrance to the summit cut will be placed a pair of gates 100 feet wide, so that if it should become necessary to draw off the water from the summit cut the level of Lake Bohio would not be affected. These gates will be at the site of a lock proposed by the French company near Obispo, with a foundation on hard rock.

CULEBRA CUT.

The summit cut is 7.91 miles long from the Obispo gates to the Pedro Miguel locks. The highest point is about 5 miles from the Obispo gates, where the bottom of the canal at the axis is 286 feet below the natural surface of the ground. This is the famous Culebra cut, though the name has often been applied only to the mile of heaviest work. There is a little very hard rock at the eastern end of this section, and the western

flores lock, with a lift varying from 18 feet at high tide to 38 feet at mean low tide. There is a good rock foundation for this lock. A spillway will be required to regulate the height of this level.

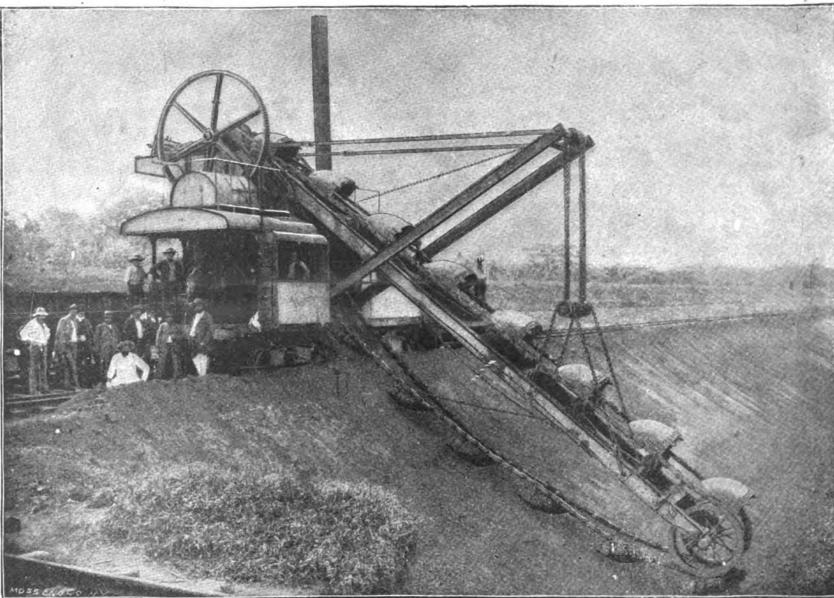
PACIFIC MARITIME SECTION.

For 4.12 miles beyond the Miraflores lock the canal extends through a low swamp country through which the Rio Grande runs. Occasional rock is found here, but the material is generally very soft and the canal has been estimated for a bottom width of 150 feet with slopes of 1 on 3. This brings the canal to a point known as La Boca where the Panama Railroad Company has constructed a large and substantial wharf. A dredged channel 200 feet wide with slopes of 1 on 3 will extend from this point 4.41 miles to the 6-fathom line in Panama Bay. The first 2 miles of this dredged channel are through flats which are bare at low water, where there is a considerable amount of submerged rock.

BOHIO DAM.

The Bohio dam is the most important structure on the line, being of great magnitude of vital necessity to the scheme, and offering many difficulties of construction. The Commission has devoted much time to the procurement of full and reliable information concerning the foundation upon which this dam must rest, and to study the various types of structures which might be adopted.

The borings made by the French engineers upon and near the line of the dam as furnished to the Commission were 21 in number. In the central part of the valley they did not go down to rock. In this case the Commission decided to do more to verify the data furnished to it, and caused a large number (86) of additional borings to be made. With the exception of seven, which were abandoned before completion on account of accidents to the apparatus or unusual difficulties of soil, all of these borings reached rock. They



EXCAVATING PLANT AT PANAMA—FRENCH EXCAVATOR, "DOWN DIGGER" TYPE.

two miles are in ordinary materials. The remainder consists of hard indurated clay, with some softer material at the top and some strata and dikes of hard rock. In fixing the price it has been rated as soft rock, but it must be given slopes equivalent to those in earth. This cut has been estimated on the basis of a bottom width of 150 feet, with side slopes of 1 on 1. While the cut would probably not be finished with this uniform slope, this furnishes a correct basis of estimate as can now be arrived at. The entire cut will be lined with masonry walls, finishing at elevation 92, 2 feet above high water, these walls having nearly vertical faces and furnishing benches 38 feet wide on either side of the canal, one of which the Panama Railroad will be laid, while it is probable that a service track will be placed on the other.

Much has been said about the instability of the Culebra cut; in point of fact, there is a clay in the upper portion of the deep cut which flows readily when saturated, but which will give little trouble if thoroughly drained; probably nine-tenths of the material would naturally be classed as hard clay of stable character; it would weather somewhat, and the surface might require some repairing with concrete in bad places, a practice common in deep cuttings in Europe. This clay disintegrates rapidly in water, and for this reason the canal prism should be confined between masonry walls. With the provision made for broad benches on each side, on which any slight slide would be arrested, it is believed that no trouble will be experienced.

PEDRO MIGUEL LOCKS.

The Pedro Miguel locks will be similar to the Bohio locks, the aggregate lift varying from 54 to 62 feet. A level of 1.33 miles long extends from the Pedro Miguel locks to the last lock, which is at Miraflores. The normal elevation of the surface of the water is 28.

MIRAFLORES LOCK.

At the end of this level will be located the Miraflores lock, with a lift varying from 18 feet at high tide to 38 feet at mean low tide. There is a good rock foundation for this lock. A spillway will be required to regulate the height of this level.

show a variety of materials—hard clay, soft clay, sand, gravel, and some mixtures of sand, clay and gravel in varying proportions. These materials are found in beds of varying shape and thickness, not distributed with uniformity and not arranged according to any general law from which can be deduced the character of the soil at points other than those actually examined. In every section constructed from the borings, strata of greater or less dimensions are found, which are permeable by water. A masonry dam founded throughout upon the rock, or an earth dam with a masonry core going down everywhere to rock, would close the valley completely and would leave no question open as to its future efficiency. In its preliminary report, the Commission based its estimates on a masonry dam. The examination of the ground had not at that time been completed. So far as they had progressed they showed a site where a masonry dam seemed the most suitable, but it was subsequently found that the depth to rock upon that site was at least 143 feet below sea level at the deepest part. It was considered best to avoid, if possible, so great a depth of foundation. A site was found a few hundred feet farther downstream where the length of the dam would be considerably greater than at the former site, but the greatest depth to rock revealed by the borings was only 128 feet below sea level. The physical features of the location admit of the construction of an earth embankment with a heavy masonry core carried down to bed rock throughout the length of the structure. For reasons of economy that type of dam is preferable to one wholly of masonry upon the new site, and is now adopted.

It is proposed to sink the foundation of the core wall by the pneumatic process at all points where the foundation bed is lower than about 30 feet below mean sea level. This requires pneumatic process to be used through a length of 1,314 feet, of which about 310 feet is at the maximum depth of 128 feet below the sea level. Where the foundation bed is above elevation 30, coffer-dams are to be used. This involves the use of coffer-

dams through a length of 324 feet, the foundation at sea level being extended 78 feet at the easterly end and 246 feet at the westerly end of the pneumatic work. The cofferdams extend to a height 8 feet above sea level. Above elevation 8 all operations would be carried on by the ordinary methods of dry work.

The width of the dam at the top is 20 feet, and its total length is 2,546 feet. The elevation of the top is 100 feet above mean sea level, affording a super-elevation of the dam of 8 feet above the highest possible water in the lake and 10 feet above the usual high water. Its total height above the lowest part of the foundation is 228 feet. The earth faces of the dam are designed to have mean slopes of one vertical to three horizontal, and to be broken by three terraces, each 6 feet wide. It is necessary to pave only the upstream face, but it is probable that both faces would be heavily riprapped with the rock spoil from the lock excavation near the westerly end. The masonry core is 30 feet thick at and below elevation 30. From that level it tapers to a thickness of 8 feet at top.

Material for the heavy fill required is found in the immediate neighborhood. The local conditions are such that not less than seven-eighths of the work could be completed without interfering with the natural flow of the Chagres. When it becomes necessary for the completion of the dam to divert the river, the unfinished Gigante spillway and, later on, the finished locks at Bohio may be employed as diversion channels.

GIGANTE SPILLWAY.

The Gigante spillway, which is a structure of considerable magnitude, is very simple. There is a good rock foundation at or above tide level for the entire length of this spillway. It will consist of a dam entirely of concrete with a crest at elevation 85, terminating in an apron at elevation 65, with a solid foundation below this level, the apron being everywhere below the present surface of the ground. The foundation, below

the total amount of excavation is 94,863.703 cubic yards, exclusive of excavation for the Bohio dam and the Gigante spillway.

LENGTH AND CURVATURE.

The location of the canal is, in general, the same as that proposed by the French company. Its total length, from 36 feet deep in the Atlantic to 36 feet deep in the Pacific, is 49.09 miles. The distance from the inner end of the harbor enlargement at Colon to the shore end of the bay channel at La Boca is 42.3 miles, of which 11 miles is the broad channel of Lake Bohio. The alignment is exceptionally good, the sharpest curve having a radius of 6,232 feet, except one at the entrance to Colon Harbor, which has a radius of 3,280 feet, but where the bottom width is from 500 to 800 feet. The total curvature in the entire length of the canal is 771 deg. 39 min.

TIME OF TRANSIT.

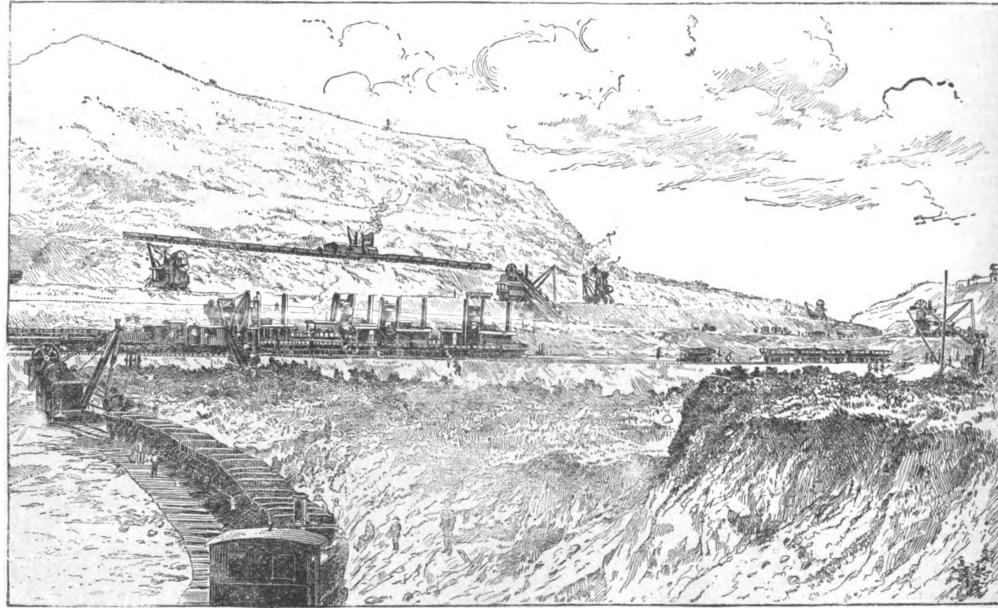
The time required to pass through the canal after completion will vary with the size of the vessel and with the number of other vessels. For the purpose of comparison the time has been carefully computed for a ship 400 feet long, 50 feet beam and 24.5 feet draft, or what may be called an averaged-sized ship. The open sea speed is taken at 12.5 statute miles, or about 11 knots per hour. The reduced speed in various parts of the canal and the delays caused by lockages and by passing other vessels have been obtained from observation of the practical working of the Sault Ste. Marie and the Manchester canals. They are as follows: In canal sections having a bottom width 150 feet, speed on tangents 8 miles per hour, on curves 7 miles per hour; in Panama Bay channel, speed 9 miles per hour; in Lake Bohio, speed on tangents 10 miles per hour, on curves 9 miles per hour; in harbors and harbor entrances, speed on tangents 10 miles per hour, on curves

THE NICARAGUA ROUTE.

The Nicaragua route attracted the attention of explorers in the early days of interoceanic canal discussion, and was regarded by many as a most favorable one. Water communication by means of a large river and lake from the Atlantic to within a short distance of the Pacific accentuates the natural advantages of this route and at the same time tends to exaggerate them and to obscure the attendant difficulties.

Lake Nicaragua is about 103 miles long. It has a maximum width of about 45 miles and an area of about 3,600 square miles. It is fairly regular in outline, with its longer axis nearly parallel to the Pacific coast, which in this vicinity has a northwesterly direction. It resembles Lake Erie somewhat in shape, but has only about one-third the area of the latter. Notwithstanding the fact that the existence of this lake had long been known, it appears that the first instrumental survey was made by the Nicaragua Canal Commission in 1898. It was then found that the bottom of the lake is about sea level over the greater part of its area, a comparatively small depression being below that level. The maximum depth is about 200 feet, and is found just south of the island of Ometepe, which has an elevation of 5,000 feet.

The surface of Lake Nicaragua is generally a little more than 100 feet above sea level. Its extreme fluctuation is not definitely known. Its annual fluctuation varies with the annual rainfall and the discharge of the streams that empty into it. These are small, and in the dry season they discharge very little. Mr. Menocal in his report for 1885 states that the lake was as high as 110.63 feet above mean sea level at the end of the wet season of 1878. This is perhaps founded on the observations of the residents of Granada, who are reported to have seen the water of the lake up to the top of the steamboat wharf at that place. This may be regarded as an approximate determination of highest



CULEBRA CUT, PANAMA SIDE, IN 1899.

elevation 65, will be put in first and before the flow of water through the present river at the site of the Bohio dam is checked. The estimated cost, including the channel ways immediately above and below it, is \$1,209,419.

PANAMA RAILROAD DIVERSION.

From Bohio to the Obispo gates the Panama Railroad must be rebuilt for 15.5 miles on a new location, with a bridge across the Chagres below Gamboa. An estimate made from approximate profiles indicates that the cost of this diversion will not exceed \$75,000 a mile, or \$1,162,500. From the Obispo gates the railroad will be carried for 6 miles on the bench formed by the retaining wall on the east side of the Culebra cut, these 6 miles being estimated to cost \$10,000 a mile, which includes only track laying, ties and ballasting. Beyond this will be a mile of light work estimated at \$25,000, while the main track will have to be raised for 2 miles farther at a cost of \$20,000. Combining these figures, the total cost of the diversion of the Panama Railroad becomes \$1,267,500.

Summing up, the total estimated cost of completing the Panama Canal is as follows:

Total estimated cost.	Miles.	Cost.
Colon entrance and harbor	2.39	\$8,057,717
Harbor to Bohio locks, including levees	11.2	11,000,359
Bohio locks, including excavation	35	11,000,000
Lake Bohio	13.61	2,038,154
Obispo gates	295,434	
Culebra section	7.91	41,411,460
Debarco locks, including excavation and dam	1.35	1,000,000
Petro Miguel level	1.33	1,192,266
Manzanares locks, including excavation and spillway	20	5,781,401
Pacific end	8.53	12,427,971
Bohio dam	6,232	6,232,000
Gigante spillway		1,290,419
Pena Blanca outlet		2,148,076
Chagres diversion		1,000,000
Panama Railroad diversion		1,267,500
Total	40.09	\$130,194,465
Engineering, police, sanitation, and general contingencies, 30 per cent.		34,038,893
Aggregate		\$144,232,358

8½ miles per hour; all statute miles. The delay caused by lockages is 3 hours and 58 minutes, and that caused by meeting other vessels, 1 hour and 14 minutes. From these data the time of transit through the canal is computed to be 11 hours and 14 minutes.

The plan recommended by the Commission is, in its general outlines, the same as the second plan of the French engineers, the one preferred by them, except for the time required for construction. The principal difference is in the height given to the Bohio dam and the important consequences which result therefrom. A marked feature of the Commission's plan is its simplicity. The increase in the depth and area of Lake Bohio renders it possible to receive the full flood discharge of the Chagres directly into it without impeding navigation and at the same time to take full advantage of favorable topographical features of the country in the subsequent discharge of the surplus waters. The Alhajuela dam becomes unnecessary for flood control, and its construction may be deferred until additional storage capacity is required as a result of a large increase in the traffic of the canal in the future. The outlet of Lake Bohio becomes a single fixed weir instead of two weirs with regulating gates and with two separate channels to the sea. A great reduction also results in the amount of excavation required to cut through the continental divide. There is a material reduction of cost.

TOTAL VALUE OF THE PANAMA CANAL.

Summing up, the total value of the property of the new Panama Canal Company is found to be:

Excavation already done.....	\$27,474,033
Panama Railroad stock at par.....	6,850,000
Maps, drawings and records.....	2,000,000

Total \$36,324,033

To which add 10 per cent to cover omissions, making the total valuation of the Panama Canal \$40,000,000.

lake level. The data for fixing the minimum level of the lake are equally uncertain; but it is stated on the authority of what are believed to be competent witnesses that it has been as low as 97 or less. These extremes have only been reached at long intervals. The fluctuations in the last three years, during which time regular observations have been taken, have amounted to only 6.09 feet.

The San Juan River, through which the lake discharges at Fort San Carlos, follows a tortuous course in a southeasterly direction and empties through several mouths into the Caribbean Sea near Greytown. The distance from the lake outlet to the mouth of the river is about 80 miles in an air line, but about 120 miles following the windings of the river; the greater portion of the valley drained being on the right bank, where the divide, a lofty mountain range, is about 50 miles distant. On the left bank the divide is only 10 to 20 miles from the river, and the crest is much lower. The Indio, which empties into the Caribbean Sea some 6 miles northwest of Greytown, runs generally parallel to the San Juan, the headwaters of some of its tributaries being only about 15 to 20 miles distant from that river.

The largest and most important tributary of the San Juan is the San Carlos. It rises in the mountains of Costa Rica, flows northeasterly and empties into the San Juan about 57 miles (measured along the windings of the river) from the lake. It is a wide, swift stream, having a drainage area of about 1,500 square miles, as determined from the best maps available. This estimate may be too great or too small, as the region has never been surveyed. The discharge varies within wide limits. It is known to have been as low as 3,000 cubic feet per second, and as high as 66,820 cubic feet per second. The estimated possible maximum is 100,000 cubic feet per second.

RAINFALL.

Along the Atlantic coast in the vicinity of Greytown and for some distance inland the rainfall is the greatest known on the continent. There is no definite dry

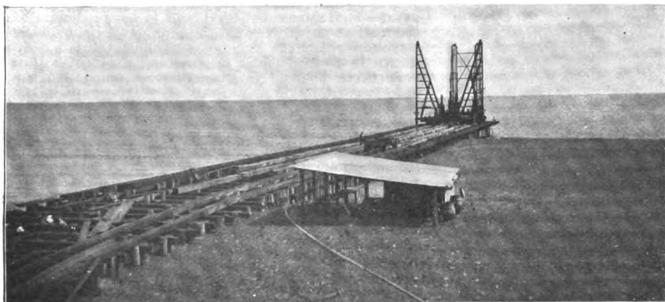
season. Rain may be expected almost any day in the year. On the other hand, the entire drainage basin of Lake Nicaragua lies in a region having a well-defined dry season. The annual rainfall near Grey Town sometimes amounts to nearly 300 inches. The average is probably 260 to 270 inches, while at Bluefields, 75 miles to the north, and at Port Limon, 70 miles to the southeast, it is less than half as much. There is a perceptible diminution in the annual rainfall as one proceeds westward to the lake. The total for the year

1899 at Grey Town was 285.93 inches, while that for the same period at Ochoa was 177.91 inches, and at Fort San Carlos 77.20 inches. For the year 1900 the annual rainfalls were for Grey Town, 276.10 inches, for Ochoa, 158.83 inches, and for Fort San Carlos, 89.34 inches. The heaviest observed rainfall in a short period was that at Silico station on Lake Silico, November 4, 1899, when 10.5 inches fell in six hours, an average of 1 $\frac{1}{2}$ inches per hour. On the same date a fall of 12.48 inches in twenty-four hours was observed

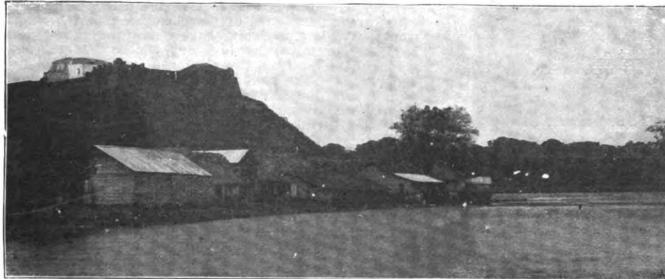
at Grey Town. A rainfall of 4 inches or more in one day is not a rare occurrence in that vicinity. In the drainage basin of Lake Nicaragua the average annual rainfall is about 65 inches.

PROJECT OF Isthmian CANAL COMMISSION, 1901.

The project of the Isthmian Canal Commission follows the general route of that proposed by the Nicaragua Canal Commission, but the depth of water in the canal has been increased, the locks duplicated and en-



THE JETTY AT GREYTOWN, LOOKING NORTHWEST—SHOWS ACCUMULATION OF DRIFTING SAND AGAINST EAST SIDE OF JETTY.



CASTILLO, LOOKING UP THE SAN JUAN—OLD SPANISH FORT ON THE LEFT; RAPIDS TO THE RIGHT.



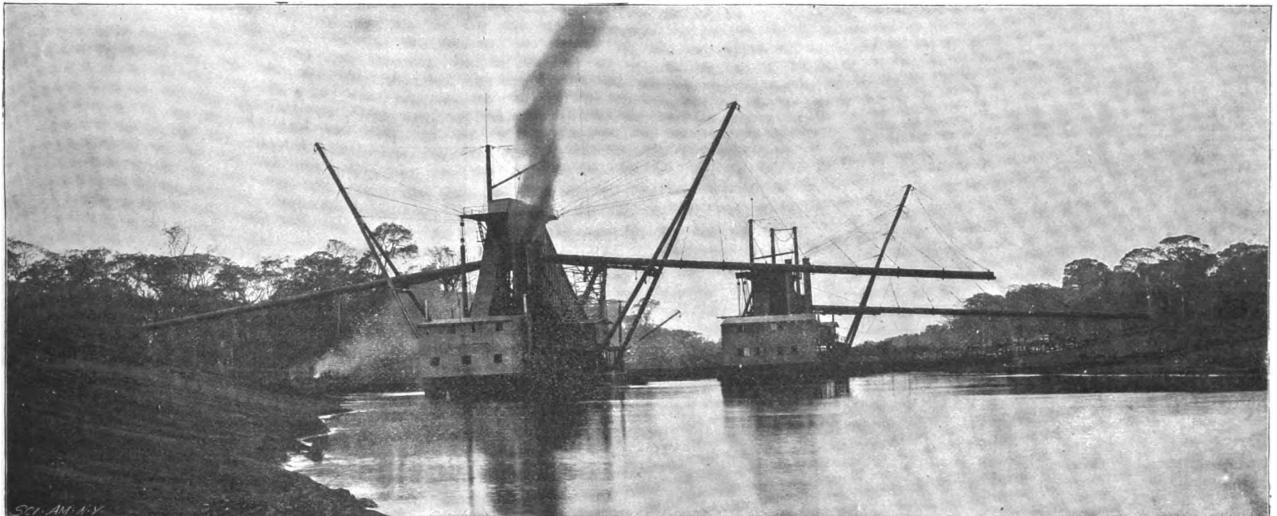
CORDUROY FOUNDATIONS FOR RAILROAD FILL ACROSS THE SWAMP.



THE MARKET IN GRANADA, NICARAGUA.



VIEW ON THE SAN JUAN RIVER AT MOUTH OF THE RIVER SAN FRANCISCO.



SUCTION DREDGES CUTTING THE FIRST MILE OF THE CANAL AT GREYTOWN.
THE MARITIME CANAL COMPANY'S PROPOSED NICARAGUA CANAL, 1889-1893.

larged, and a new and better site for a dam in the San Juan found. The project is as follows:

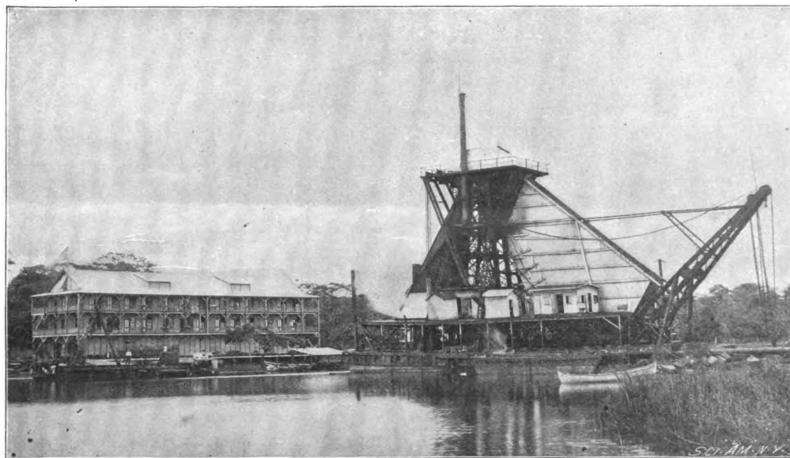
GREY TOWN HARBOR AND ENTRANCE.

Beginning at the 6-fathom curve the entrance to the canal will lie between two jetties running nearly north and south, about $1\frac{1}{2}$ miles northeast of Grey Town and passing close to the most westerly bend of the lower San Juan, near its entrance to Harbor Head Lagoon. The entrance to the harbor is to be 500 feet wide and not less than 35 feet deep at low water. At the shore

15 feet, with side slopes of 1 on 3. The crest of the embankments will be 5 feet above the highest flood levels. These dimensions apply to all sections of the canal where embankments are required.

SECTION FROM LOCK NO. 1 TO LOCK NO. 2.

From lock No. 1 the line continues in the general direction of the Misterioso for about 2 miles. It then crosses the Pescado, which drains a swampy region to the southward, and enters the region drained directly into the San Juanillo. It crosses this stream about 2



MARITIME CANAL COMPANY'S STOREHOUSE AND DREDGE AT LA FE, GREYTOWN.

end of the jetties the line swings to the right on a curve of 4,175 feet radius and then passes into a tangent across the existing Grey Town Lagoon. For a distance of 2,500 feet from the inner end of this curve the width is continued at 500 feet. It is then widened to 800 feet for a further distance of 1,000 feet, in order to furnish a turning basin. It is then gradually reduced to 150 feet, the regular width of canal at the bottom. This width is reached 2.15 miles from the 6-fathom curve in the Caribbean. The head of the east jetty is to extend to this curve and is the zero point to which distances along the canal are referred. The harbor thus formed is well protected. The estimated cost of the entrance and harbor is \$2,198,800.

SECTION FROM HARBOR TO LOCK NO. 1.

From the harbor the line runs in a southwesterly direction, crossing the San Juanillo to the low, swampy ground along the Rio Misterioso. At a distance of 7.56 miles from the entrance the line swings to the left on a curve of 11,459 feet radius, and then follows a straight line in a direction a little west of south through the first lock, which is located 9.59 miles from the entrance.

Lock No. 1 is located in a hill on the southwest side of the Misterioso, and will have a lift of $36\frac{1}{2}$ feet

miles from the place where the San Juanillo leaves the San Juan, and then traverses about a mile of swamps and low hills, passing into the valley of the Rio Negro, a tributary of the San Juanillo, behind the hills at Punta Petaca, where it is about 1 mile distant from the San Juan. It then continues in the valley of the Rio Negro, crossing it about a mile east of the Negro hills in which lock No. 2 is located. There are two curves on this section, each of 8,594 feet radius. The section is generally swampy, but in the Rio Negro Valley the line cuts through some hills.

The canal surface in this section is to be maintained at a minimum elevation of 36 feet above mean tide. The flood levels immediately above lock No. 1 appear to be about 31 feet above the same reference and immediately below lock No. 2 about 43 feet above it. The region communicates freely with the San Juan during high water in the latter, whence most of the flood water comes, and also receives considerable drainage from the mass of hills north of the line. The embankments have not only to maintain the canal level, but are also required to exclude floods from the San Juan on the upper portion of the section. On the north side of the canal hills form the greater part of the line of protection, although a few swamps have to be crossed by embankments. On the south side the Silico hills

material excavated would not be available even if suitable, which it seldom is. They will be formed from clay borrowed from the hills.

The swamp level near lock No. 1 is at about elevation 16, and at lock No. 2 about elevation 38. Almost the entire area within the embankment lines (some 12 or 13 square miles) will be below the level of water in the canal. The total drainage tributary to the section is probably 25 square miles. A waste way is required which will be located at or near the Silico hills where the flood level in the San Juan is below the canal level. It is to be a simple overflow weir with crest at elevation 36, the minimum canal level, and to have a length of 600 feet, which will prevent the canal level rising above elevation 37.5. The assumed maximum rainfall is 12 inches in twelve hours, all reaching the pool within twenty-four hours. No site with rock foundation has been found for this waste way. It will be built in the clay hills. Lock No. 2 will have a hard rock foundation. The lift will $18\frac{1}{2}$ feet, from elevation 36 to elevation 54.5.

The length of this section is 10.96 miles. A part is through swamps, requiring side slopes of 1 on 3. In the remaining portion the cross section is reduced to the standard adopted for firm earth.

SECTION FROM LOCK NO. 2 TO LOCK NO. 3.

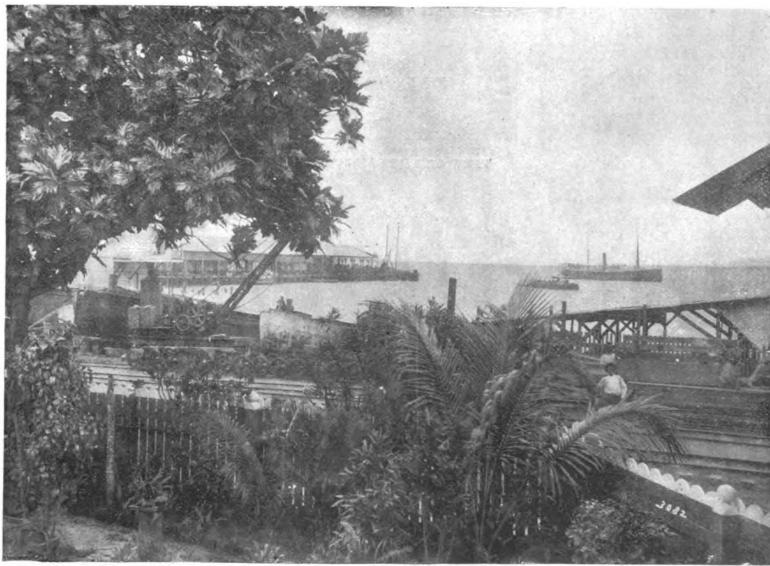
The general direction of the line in this section is a little north of west. It leaves the Rio Negro Valley near lock No. 2, and passes behind the Serapiqui hills, which were formerly supposed to be connected with the high range to the northward. At this point the line is more than a mile from the San Juan. A short distance farther west the route crosses the Tamborcito ridge, after which at short intervals it crosses the Tambor Grande and San Francisco ridges. A line located around the ends of these ridges near the river would have inadmissibly sharp curvature, and would be liable to injury during river floods. If carried across them far from the river the cuttings would be very heavy. The line projected by this Commission is at a safe distance from the river, and although involving heavy work, avoids the much heavier work that a location farther from the river would require. The deepest cut on the center line of the canal is 297 feet, in the Tamborcito ridge.

Riprap protection against river floods will be required in the swamp levels of those localities where the line approaches close to the river. After crossing the San Francisco River the line follows a westerly direction to the Danta, which it first crosses about 2 miles from the San Francisco. It then follows the valley of the Danta, which it crosses several times, to lock No. 3. This portion of the line passes through a swampy region with occasional low hills.

The cut in the Tamborcito ridge is the deepest on the route, and will consist largely of hard, basaltic rock. It is, however, only about 3,000 feet from the foot of the ridge on the east side to the foot on the west, and the crest is narrow.

There are eight curves on this section of the canal, of which one has a radius of 4,911 feet, four of 5,730 feet, one of 6,876 feet, one of 8,594 feet, and one of 11,459 feet.

Since the line was laid out borings have shown that deep sand exists under a part of that portion of it lying between the Tambor Grande and the San Francisco, its upper surface being near the canal bottom. It is probably a former bed of the San Juan River. Recent surveys and borings have shown that this material can be avoided by a location farther inland, but as it has not been practicable to take new borings across the ridges on the new lines, the estimates are

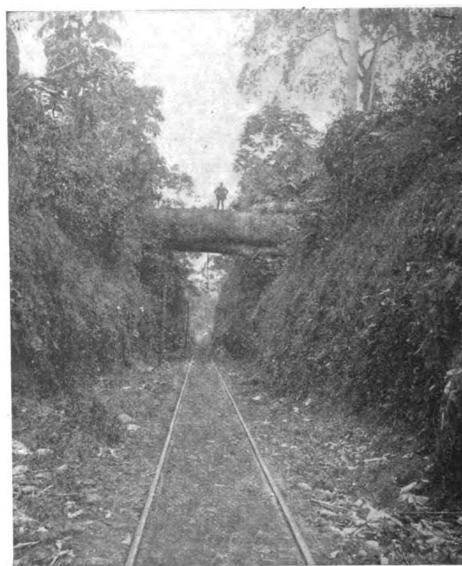


PORT LIMON, COSTA RICA.

above mean low tide. This lock, as well as all others, will be in duplicate and founded on rock. The swamps communicate freely with the San Juan River through the San Juanillo and other streams, and the flood level rises at lock No. 1 to about 11 feet above sea level.

It is proposed to exclude flood water from the canal on this section. This will require embankments on both sides. They are to have a minimum top width of

protect the level for several miles, but to the westward of them are long stretches of swamp with soft bottom where embankments are required. These embankments constitute one of the difficulties of this section. The estimates provide for the removal of the soft material for a width of 30 feet at bottom to make the embankments safe when built. They are located in most places so far from the canal line that the ma-



CUT IN EARTH AT LA JUNTA ON THE COSTA RICA RAILROAD.

made on the line that is laid down, and include an allowance for puddling the bottom of the canal where needed. A small amount of permeable material is also shown by the borings in a hill crossed by the canal line near the Florida Lagoon, and the estimates provide for puddling at this locality.

The surface of the swamp near lock No. 2 has an elevation of about 38 feet above the sea level, and gradu-

ally rises to elevation 45 in the Florida Lagoon, near lock No. 3. The line intercepts the drainage from about 75 square miles lying to the northward, and crosses the Guasimo, San Gerónimo, Tambor Grande, San Francisco, and Danta, as well as a number of small creeks. The beds of the larger streams are from 15 to 20 feet below swamp level. The swamp bottoms are of clay silt, which may settle under the embankments, but should not offer serious difficulties to good construction. The level of the canal is to be maintained at the minimum elevation of 54.5 feet, submerging all the swamps. The flood levels appear to be about 53 feet at the Serapiquí and 56 feet in the San Francisco region, the latter being 1½ feet above the minimum stage in the canal. In order to diminish the currents through the narrow connecting channels three waste ways are provided, one in the Serapiquí Hills, 500 feet long, one of the same length in the west flank of Tamborito, and one of 1,000 feet near the Danta. With these waste ways it is estimated that the water in the canal will never rise more than 2½ feet above the normal stage.

The waste ways are designed to be plain overflow weirs built of concrete, with the crests at elevation 54.5, the minimum canal level. At rare intervals the crest of the Danta waste way may be submerged by the San Juan floods, but the amount of water taken into the canal over it will be so small that no trouble is apprehended. The borings made at the site of the Danta waste way show unfavorable material for foundations, involving an additional expense for safe construction, for which provision has been made in the estimates. Lock No. 3, which terminates this section, is located on a rock foundation, having a lift of 18½ feet, viz., from elevation 54.5 to elevation 73 at minimum canal level. The length of this section is 16.75 miles.

SECTION FROM LOCK NO. 3 TO LOCK NO. 4.

Westward from lock No. 3 the line follows down the valley of Embankment Creek to within about 1,700 feet of its mouth, and then crosses some hills and the Machado to lock No. 4. There are two curves on the section having radii of 11,459 feet each. The excavation will be mainly in firm earth with standard slopes to correspond. Some rock will be found near the site of lock No. 4, and soft mud in crossing the valley of the Machado. The drainage area tributary to this section has not been well determined, but is taken at about 9 square miles, about 1 square mile of which will be submerged. It is proposed to control the surface of the pool, between elevations of 73 and 76 feet, by a weir 300

feet long, located in a hill a short distance east of Machado.

Two embankments will be needed between the canal and the San Juan River, one across Embankment Creek, the other across the Machado, where the crest will be about 31 feet above the bottom of the stream and about 24 feet above the swamp level. The borings

SECTION FROM LOCK NO. 4 TO THE SAN JUAN RIVER.

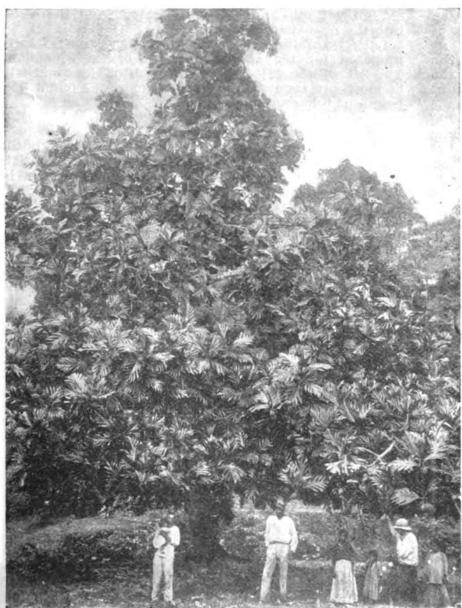
Westward of lock No. 4 the line passes through a rough, hilly region where deep cutting is encountered. About three-fourths of a mile west of the lock the depth to the bottom of the canal on the center line is 218 feet below the surface. The borings show a strat-



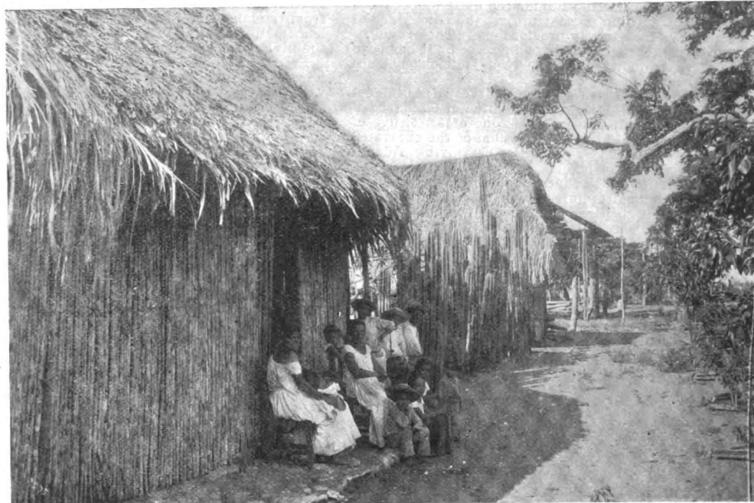
SAN JORGE LANDING ON THE WEST SHORE OF LAKE NICARAGUA. OMETEPE MOUNTAIN, 5,350 FEET, IN THE DISTANCE.

show the surface material in this swamp to be soft, and some of it will have to be excavated, so that the embankment may rest on firm material. Lock No. 4 is located in a hill immediately west of the Machado. It is proposed to control the surface of the summit level of the canal between the elevations of 104 and 110 feet; hence this lock is designed to have a variable lift, the maximum being 37 feet and the minimum 31 feet. The length of this section is 2.77 miles.

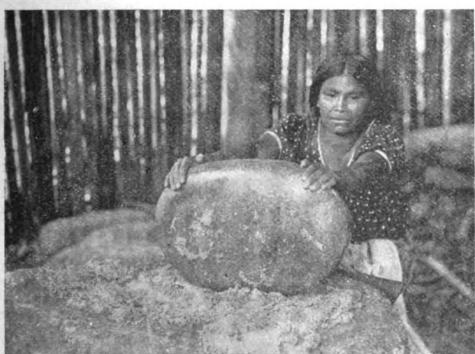
um of clay 10 feet thick, from elevation 65 to elevation 55, the top being about 4 feet below the bottom of the excavation. About 1 mile farther westward is another cut 170 feet deep on the center line, with a clay stratum 10 feet thick, the upper surface being at elevation 89. In the latter case the clay stratum is in the wetted prism of the canal. In both cases there is rock overlying the clay. It is supposed that the rock is a volcanic overflow. Where the clay shows in the wetted



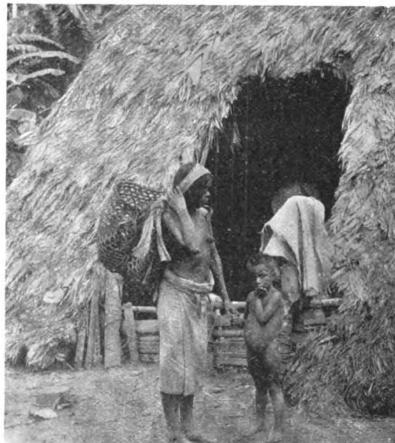
BREAD FRUIT TREE.



NATIVE GROUP, WITH THATCHED HUT AND CACTUS HEDGE.



THE MILLSTONE AND POWER PLANT.



TELEMANCA MOTHER AND CHILD.



WASHING SCENE, COSTA RICA.

SCENES IN THE REGION OF THE NICARAGUA CANAL.

prism, slopes of 1 on 1 are provided for both rock and clay.

The section forms a part of the summit level, and has two curves, each of 5,730 feet radius. The point where it enters the San Juan River is 46.17 miles by the canal line from the 6-fathom curve in the Caribbean Sea. The upper end of this section is 3.3 miles by the river from the dam site at Conchuda. This dam will maintain the summit level, regulated by waste ways at the dam and in the hills a short distance southwest on the Costa Rica side. The dam, waste ways, and system of regulations are fully described elsewhere. The length of this section is 5.30 miles.

SAN JUAN RIVER SECTION.

This section embraces that portion of the river from the point where the canal enters it above the dam to Lake Nicaragua. As already stated, the San Juan River above the mouth of the San Carlos is practically free from sediment, and in this respect is well adapted for slack-water navigation. It is very crooked, however, the curves being so sharp in places that the nat-

the east end of the western division of the canal. The bottom from Fort San Carlos to deep water in the lake consists of soft mud 6 to 17 feet deep, underlaid by hard clay and sand. The mud is so soft in places that it is difficult to determine its surface. The steamboat navigating the lake pushes it way through several feet of it when the lake is low. This material will take a flat slope, and after a channel is excavated through it there will be some expense for maintenance.

On the west side the excavation in the lake commences 1.52 miles from the shore. It will consist chiefly of rock, and as it is submerged, is estimated at the price for rock excavation under water. The material excavated from the west side of the lake can be wasted where it will form jetties for the protection of this entrance. The bottom width of the channel in excavation in the lake, both on the east and west sides, will be 300 feet.

The total length of the lake division is 70.51 miles.

LAKE NICARAGUA TO LOCK NO. 5.

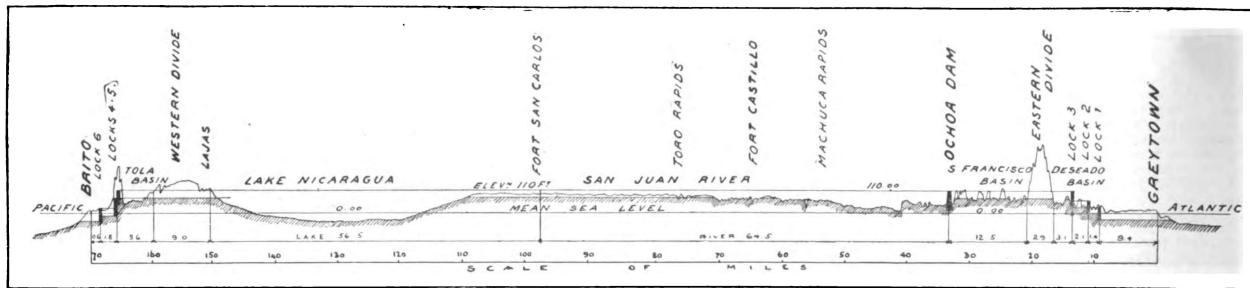
The entrance to the canal from Lake Nicaragua is

will not be heavy and can easily be protected. This section contains a single curve of 4,982 feet radius. A by-pass in lock No. 5 will provide water for this level. A small waste way will discharge surplus waters into the Rio Grande. The excavation will consist mainly of sandstone much disintegrated near the surface, but less so farther down.

Lock No. 6 is located in a small hill on the south side of the Rio Grande about one-half mile above the mouth of the Rio Tola. The foundation is on rock. The lift is 28½ feet. The length of this section is 2.04 miles.

LOCK NO. 6 TO LOCK NO. 7.

In this section the line crosses the bed of the Rio Grande several times, and short embankments 20 to 30 feet in height will be required; elsewhere the embankments will be unimportant, the grade line being low, as in the preceding section. This section contains a single short curve of 5,056 feet radius. The excavation will be mostly in sandy earth, except in the vicinity of the lock sites. While the excavation is sandy, it contains



PROFILE OF THE NICARAGUA CANAL AS PROPOSED BY THE MARITIME CANAL COMPANY, 1893.

ural channel, even if deep enough, would be difficult for large ships to navigate. Cut-offs have been located in such places, improving the course of the channel and reducing the sailing distance. These improvements leave 54 per cent of the total distance from the dam to the lake in curvature. Except in a few cases the radius exceeds 5,000 feet, but in the section between the Machuca and Castillo Rapids the limit was reduced to 4,045 feet. In the present project the curves are of larger radius than in any previous one. They could be improved, but the cost would be increased. It has been the governing motive to preserve a judicious balance between curvature and cost.

In this section there are four curves of 4,045 feet radius, one of 4,297, one of 4,911, three of 5,298, six of 5,730, two of 5,927, four of 6,876, one of 8,385, five of 11,459, and one of 17,189. The bottom of the excavated channel is established at elevation 69, giving a depth of 35 feet when the lake is at 104, its lowest stage. From the dam to the Machuca Rapids the general direction of the channel is northwesterly. The dam raises the water so as to permit a material straightening of the line on this part of the section with but little excavation. At the Patricia Rapids (in the fifty-ninth mile) the bed of the river rises above the grade of the

about 1,100 feet north of the mouth of the Rio Las Lajas. The line extends in a southwesterly direction, following first Las Lajas, which it crosses four times in a distance of 1½ miles, then following the general course of a small tributary, called the Guiscoyol, to the continental divide. The surface of the ground from the lake rises gradually until the divide is reached at elevation 153, a distance of about 5 miles from the lake shore. The highest point on this section is a small projecting hill three-fourths of a mile east of the divide, at elevation 156 on the center line.

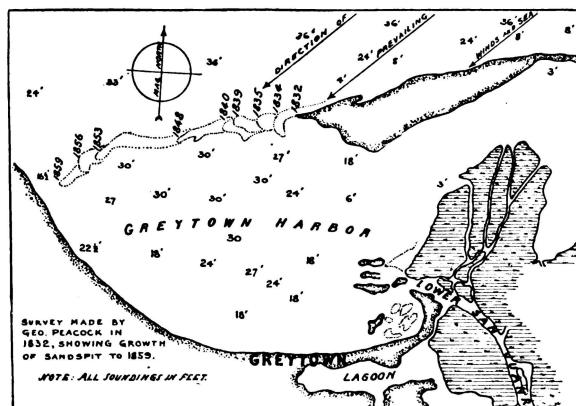
From the divide the line follows the valley of the Espinal to the Rio Grande, and then continues in the valley of the latter to the Pacific. From the mouth of the Espinal to lock No. 5 the valley of the Rio Grande is narrow and crooked, with hills on either side rising to elevations of 150 feet and upward. Here the line passes through several spurs, with rather deep but short cuts. The most important feature of this section is the cut through the west divide. Its maximum depth on the center line of the canal is 87 feet; for a distance of about 3 miles the average cut is about 75 feet. The rock is of all degrees of hardness from partially disintegrated sandstone to hard trap. Lock No. 5 is located in a hill on the north side of the Rio

enough earthy material to form water-tight embankments. A new channel will have to be provided for the Rio Grande for nearly the entire distance. This will receive the drainage from the north side of the valley, including that of the Tola. On the south side the drainage will be received into the abandoned bed of the Rio Grande, and thence discharged into the canal. A waste way located near the upper end of the section will discharge surplus water from the canal into the new channel of the river.

Lock No. 7 is located in a hill at the site formerly proposed for the south abutment of La Flor dam. The lift will be 28½ feet. The prism of the canal will be mostly in sandy silt with side slopes of 1 on 3. The length of this section is 1.83 miles.

LOCK NO. 7 TO LOCK NO. 8.

The conditions in this section are almost exactly the same as in the preceding one. The material consists chiefly of light sand mixed with loam, which can be dredged by machines taken through lock No. 8 after the latter is built. It contains two short curves of 5,730 feet radius. A small waste way is located near the upper end of the section where the canal is entirely in excavation. It will not have a rock foundation, and

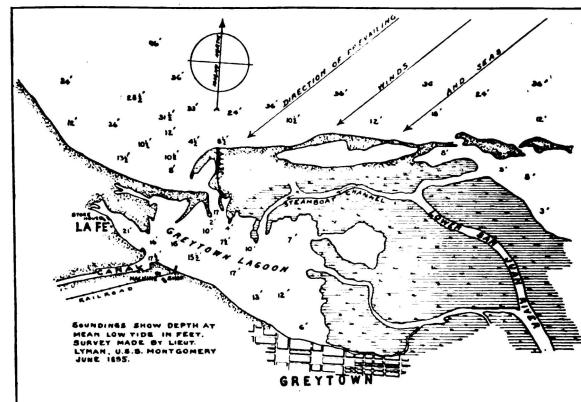


GREYTOWN HARBOR IN 1892. SHOWING GROWTH OF SAND SPIT TO THE WESTWARD UNDER ACTION OF PREVAILING TRADE WINDS.

channel bottom, and excavation is required thence to deep water in the lake.

LAKE NICARAGUA SECTION.

The line enters the lake on a curve of 11,459 feet radius, and then continues on a tangent, passing southward of the Balsillas Islands and northward of the Solentiname group. Near the latter it crosses a submerged channel, where for a short distance no excavation will be required, and, passing around a short curve in deep water, enters a second tangent, where some excavation is required for a distance of 10.77 miles. This tangent continues to the vicinity of the mouth of Las Lajas, on the west side of the lake. The lake bottom on the sailing line lies below the grade of the canal bottom for a distance of 41.78 miles; the remainder, 28.73 miles, will require excavation. On approaching the mouth of Las Lajas, the line swings to the westward in deep water to the long tangent at



SITE OF GREYTOWN HARBOR (NOW A LAGOON) IN 1895. SAN JUAN DELTA HAS EXTENDED OUT TO SAND SPIT AND HARBOR HAS SHOALLED TO 10 FEET.

Grande at Buen Retiro, and will have an excellent rock foundation. On the south side of the lock a small dam will be required across the river to the adjacent hills to maintain the summit level. This dam is designed to be of earth with a masonry core wall extending to rock. The lock will have a variable lift from 22½ to 28½ feet, depending on the height of the lake. The section contains four curves with radii of 17,189, 5,730, 5,209, and 5,056 feet, respectively. Three of these are between the divide and the lock. The length of this section is 9.09 miles.

LOCK NO. 5 TO LOCK NO. 6.

The valley or gorge of the Rio Grande gradually widens in this section, opening into the so-called Tola Basin. The soil of the Rio Grande Valley is a light, sandy loam, readily acted upon by currents. The grade of the canal is established so low that the prism will be almost wholly in excavation, and the embankments

will be merely a depressed section of canal bank with protected surface.

Lock No. 8, which connects with tide water, is located in a projecting spur, and will have a rock foundation. Its lift will vary with the tide from 28½ feet at mean low water to 20½ feet at mean high water. The length of this section is 2.43 miles.

LOCK NO. 8 TO THE PACIFIC.

This includes a short section of the canal proper and an artificial harbor at Brito. The excavation in this section consists mostly of sand. Some rock will be encountered near the lock site. The entrance to the harbor will be straight and have a width of 500 feet on the bottom. The length of this section to the 6-fathom curve in the Pacific is 1.15 miles. The prism, except near the lock, will have side slopes of 1 on 3. The total distance from Lake Nicaragua to the 6-fathom curve in the Pacific is 17.34 miles.

HARBORS.—LACK OF HARBOR FACILITIES.

As there is no natural harbor at either end of the proposed canal artificial harbors will have to be constructed. This lack of harbor facilities will be seriously felt on the east side in the early stages of the work, as the difficulties and expense of landing material before the harbor can be constructed are great.

GREY TOWN HARBOR.

A fine harbor once existed at Grey Town, with about 30 feet of water at the anchorage and in the entrance. This was not such as is often found at the outlet of a large river like the San Juan, where the current scours an entrance, but rather a bright or protected area formed on the lee side of a sand spit which was itself built by the action of the waves and sea currents acting under conditions which favored such formation. A study of the various maps of Grey Town from the earliest to the latest reveals, it is believed, the processes by which natural forces acting on the movable sands composing the delta of the San Juan River have formed successively in ages past harbors which were afterward converted into lagoons or lakes. The process seems still to be going on, and Grey Town lagoon is the latest development. Ibo, Barco, Sucio, and Shepherds lagoons were probably formed in the same way and by the same agencies.

The harbor which this Commission proposes at Grey Town will have a length of 2,500 feet and a width of 500 feet, widened at the inner end to 800 feet in order to provide a turning basin. The depth throughout the harbor and entrance will be 35 feet. The entrance will be located about one mile east of the old jetty of the Maritime Canal Company.

BRITO HARBOR.

The Rio Grande empties into the Pacific Ocean at Brito, close under the rocky headland of that name. At low water in the dry season there is about 3 feet depth at the entrance, but as the tide rises and falls from 8 to 10 feet the depth is much increased at the high stage.

REGULATION OF LEVEL OF LAKE NICARAGUA.

The summit level of the canal is the surface of the water in the lake. A dam across the San Juan River at Conchuda, 52.9 miles from the lake, extends the summit level to that point. In other words, if a dam be built at the Conchuda site an arm of the lake will reach to it, carrying the lake level during a period of no discharge to the same point. The canal will leave this arm of the lake at a point 3.3 miles upstream from the dam. These are general conditions which must be preserved, and the problem of the regulation of the lake level involves the control of the latter within such limits, more or less exact, as will never permit the navigable depth of the summit level to be anywhere less than 35 feet on the one hand, nor permit the lake to rise materially beyond determinate elevation on the other. This regulation can be accomplished by the construction of dams across the Rio Grande west of the lake and across the San Juan on the east side, both being designed with suitable waste ways for the discharge of surplus water, or all the surplus water may be wasted through the San Juan. As wastewaters at or near the Conchuda dam may be given sufficient capacity to discharge all the wastage, and as the latter may readily be discharged through the lower San Juan, the entire regulation works are designed to be located at or in the immediate vicinity of the Conchuda dam.

CONCHUDA DAM.

The most important structure on the route is the Conchuda dam. Before deciding on its location a large number of borings were made to ascertain the depth to suitable hard rock for the foundation, both at the Conchuda site, and at the one near Boca San Carlos suggested by the Nicaragua Canal Commission. At the latter site the greatest depth to hard rock is 120 feet below the surface of the river at low stage. At the Conchuda site the greatest depth to hard rock is 82 feet, which is very important, because the foundations will probably have to be placed by the compressed-air process, and the depth is well within that at which the foundations of many bridge piers have been built by the same method.

The portion of the dam across the river and the swamp on the Costa Rica side, for a total distance of 731 feet, will consist, below low water, of caissons placed close together with the joints between them sealed. Upon the platform thus made the part above low water will be built as a continuous monolithic structure and will support the sluices already mentioned. From each end of this portion the dam will be built for a further distance of 100 feet into the hillsides in open excavations and with cross section designed to sustain the full head of water. Core walls extend 100 feet farther on the Costa Rica side and 240 feet on the Nicaragua side. The total length of the dam, including core walls, will be 1,271 feet. The foundation is on hard rock for the entire length.

In its preliminary report this Commission estimated the time for completing the entire work on the Nicaragua route at about ten years. This was based on the expectation that two years would be required for preparatory work and eight years to construct the dam at Boca San Carlos, which would be begun only after a temporary harbor at Grey Town was constructed and other work done. A more favorable site for the dam having been found at Conchuda, its construction is no longer the controlling feature. It is estimated that this dam can be built in four years.

RAILROAD.

A railroad for construction purposes will be necessary, and provision has been made for building one from Grey Town to the mouth of the Sabalos River, and from the west shore of the lake to Brito. The intervening space can be traversed by boats, the river between Fort San Carlos and the Sabalos being deep enough to accommodate, without improvement, such vessels as can reach the deep water of the lake from the San Juan. It is possible that the portion of the railroad between the Conchuda dam and Sabalos might be dispensed with, as the work between those points is almost entirely in the river, but it was thought best to provide convenient communication between the two oceans, as a transfer of material and men from the

east to the west side of the lake, or from the west to the east side, might become important. The portion of the river between the dam and Sabalos is navigable only for small steamers.

The railroad has been located on the south side of the canal, with the grade not exceeding 0.5 per cent. It is to be of standard gauge, supplied with sidings, stations, and water tanks, and fully equipped with the necessary rolling stock. The estimate is made on the basis of \$75,000 per mile for the railroad completed and ready for operation.

Summing up the various items, the total estimated cost of constructing the Nicaragua Canal is as follows:

Total estimated cost.	Miles.	Cost.
Grey Town Harbor and entrance	2.15	\$2,198,860
Section from Grey Town Harbor to lock No. 1, including approach wall to lock	7.44	4,899,887
Diversion of lower San Juan	.....	10,100
Diversion of San Juanillo	.....	116,750
Lock No. 1, including excavation	20	5,19,080
Section from lock No. 1 to lock No. 2, including approach walls, embankments, and waste way	10.96	6,296,632
Lock No. 2, including excavation	20	4,050,270
Section from lock No. 2 to lock No. 3, including approach walls, embankments, and waste way	16.75	19,330,054
Lock No. 3, including excavation	20	8,832,745
Section from lock No. 3 to lock No. 4, including approach walls, embankments, and waste way	2.77	4,310,580
Lock No. 4, including excavation	20	5,655,871
Section from lock No. 4 to San Juan River, including approach wall and embankments	5.30	8,579,431
Conchuda dam, including sluices and machinery	.....	4,017,030
Auxiliary waste way, including sluices, machinery, and approach walls	.....	2,045,322
San Juan River section	46.17	23,153,670
Lake Nicaragua section	70.51	7,867,911
Lake Nicaragua to lock 5, including approach wall to lock and receiving basins for the Rio Grande and Chocoluta	9.09	19,566,575
Diversion of Las Lajas	.....	190,382
Lock near Boca Retiro, including excavation	.....	4,913,512
Section from lock No. 5 to lock No. 6, including approach walls and waste way	2.04	3,259,233
Lock No. 6, including excavation	20	4,368,667
Section from lock No. 6 to lock No. 7, including approach walls, embankments, and waste way	1.83	2,999,710
Diversion of Rio Grande	.....	176,180
Lock No. 7, including excavation	20	4,769,502
Section from lock No. 7 to lock No. 8, including approach walls, embankments, and waste way	2.43	1,787,493
Diversion of Rio Grande	.....	117,380
Lock No. 8, including excavation	20	4,920,859
Section from lock No. 8 to Brito Harbor, including approach walls	23	553,476
Brito Harbor and entrance, including jetties	22	1,560,470
Railroad, including branch line to Conchuda dam site, at \$75,000 per mile	17.34	7,575,000
Total	186.66	\$158,220,052
Engineering, police, sanitation, and general contingencies, 20 per cent	.....	31,644,010
Aggregate	.....	\$189,864,062